Fundamentals of Asset Management

Step 7. Optimize Operations & Maintenance (O&M) Investment

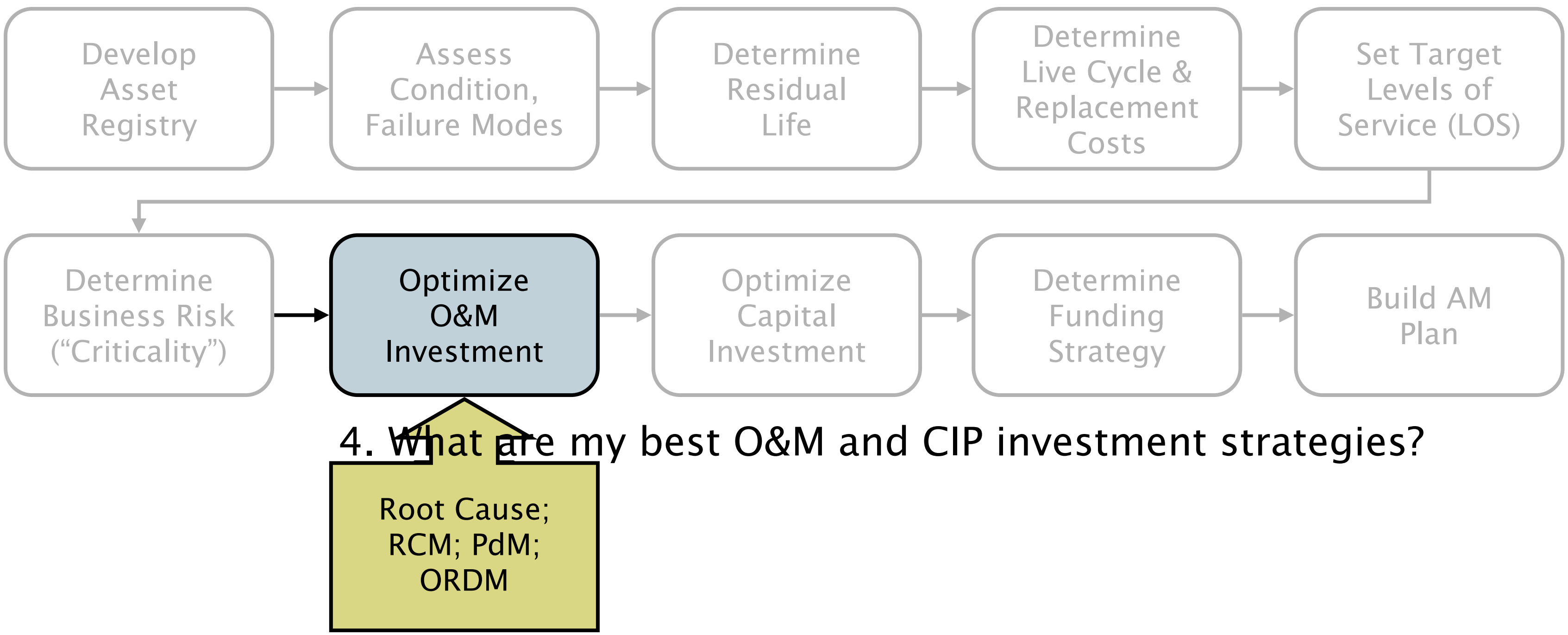
A Hands-On Approach

Tom’s bad day…

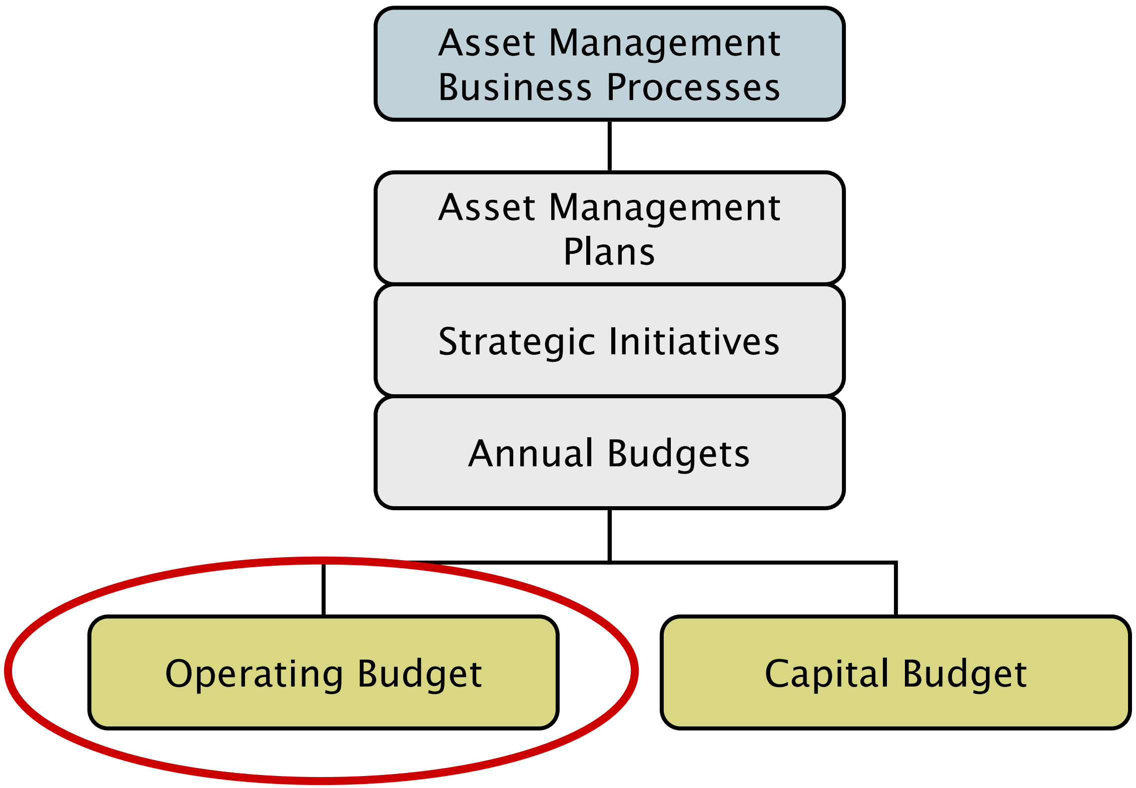
Fourth of 5 core questions

4. What are my best O&M and CIP investment strategies?
   - What alternative management *options* exist?
   - Which are the *most feasible* for my organization?

AM plan 10-step process



Recall view 4: Management framework

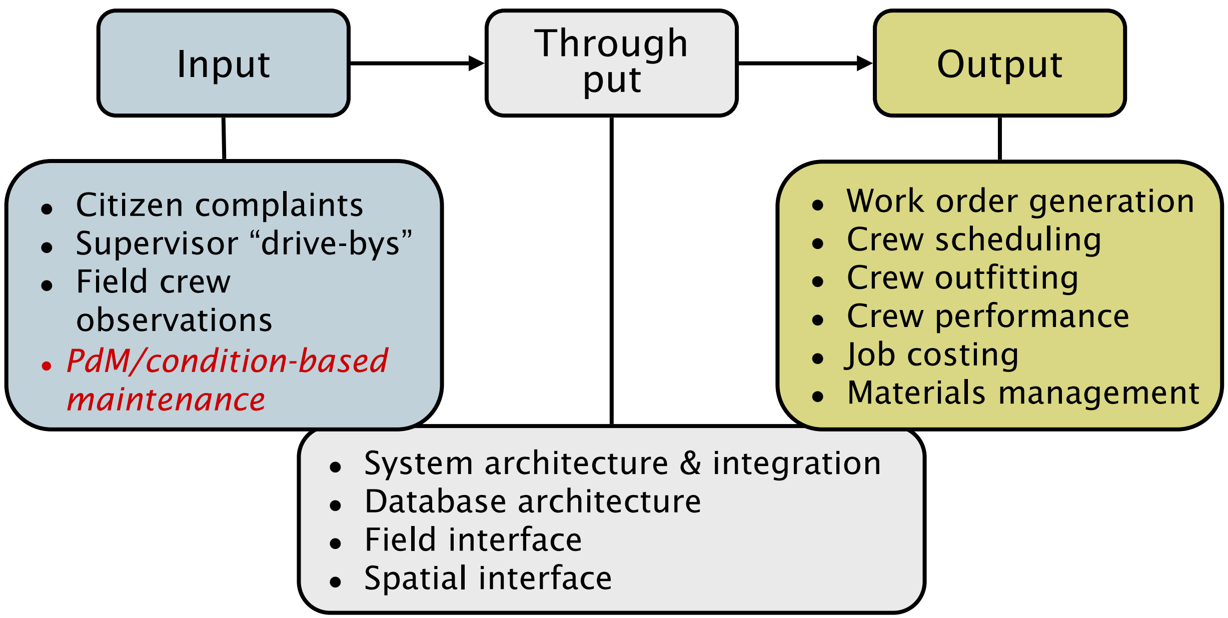


Definition

Maintenance - normal support, periodic and minor in nature, required to sustain performance and functionality of an asset consistent with design, manufacturer, and operational requirements

What triggers a work order?

Computerized Maintenance Management System (CMMS)



Importance Of The Work Order: Asset Level

WORK ORDER

Type: PM or UM

- Estimated bill of quantities
- Actual
  - Labor
  - Plant
  - Materials
- Procedure followed
- Failure mode noted
- Primary cause of failure

Memos

- Impact on customers
- Unproductive time
- Other issues

Tells us planned (PM) or unplanned (UM) maintenance costs

Builds life cycle cost history; ties to warehouse management

Tells us actual direct costs of activity

Tells us the activity used; necessary for activity analysis

Useful in *failure mode analysis*

Necessary for *causal analysis*

Indirect costs on business; impact on customers (*consequence analysis*)

Used in *efficiency analysis*

Data feedback enables substantive analysis

Bottom-line maintenance “KPIs” from an AM perspective

Metric	*Definition*	*Target*
Availability	The portion of time that a plant or major system is available for producing output of the required quality and quantity	95 – 99%
% Failure analysis	The portion of equipment downtime events that undergo a thorough analysis of failure modes, effects, and root causes	85 – 100%
% Planned work	The portion of corrective maintenance work hours that are planned and scheduled in advance (not unplanned breakdowns)	85 – 95%
% Overtime	The portion of maintenance work hours that are performed at an overtime rate	5 – 8%
Relative maintenance cost	Annual maintenance spending as a percentage of asset replacement value of the plant being maintained	1.5 – 2.5%
Technician productivity	The percent of work hours spent on productive activities versus nonproductive (rework, waiting for parts, etc)	70 – 85%
% Rework	The portion of maintenance work that has to be redone due to poor installation, shoddy workmanship or incorrect diagnosis	2 - 5%

Importance of the work order: Portfolio level

WORK ORDER

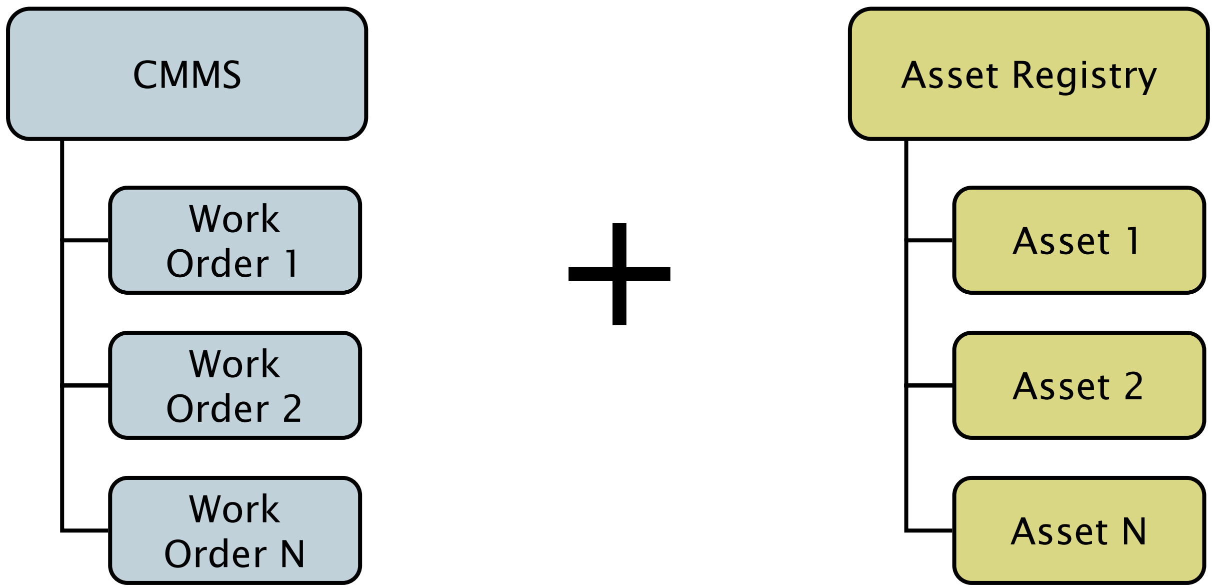
Asset details

- Type
- Category
- Size
- Condition
- Performance history
- Failure modes

Asset-linked costs enable significant analysis…

1. What type of sewer suffers the greatest number of blockages caused by tree roots?
2. How many failures are experienced by water mains of different ages in different ground conditions?

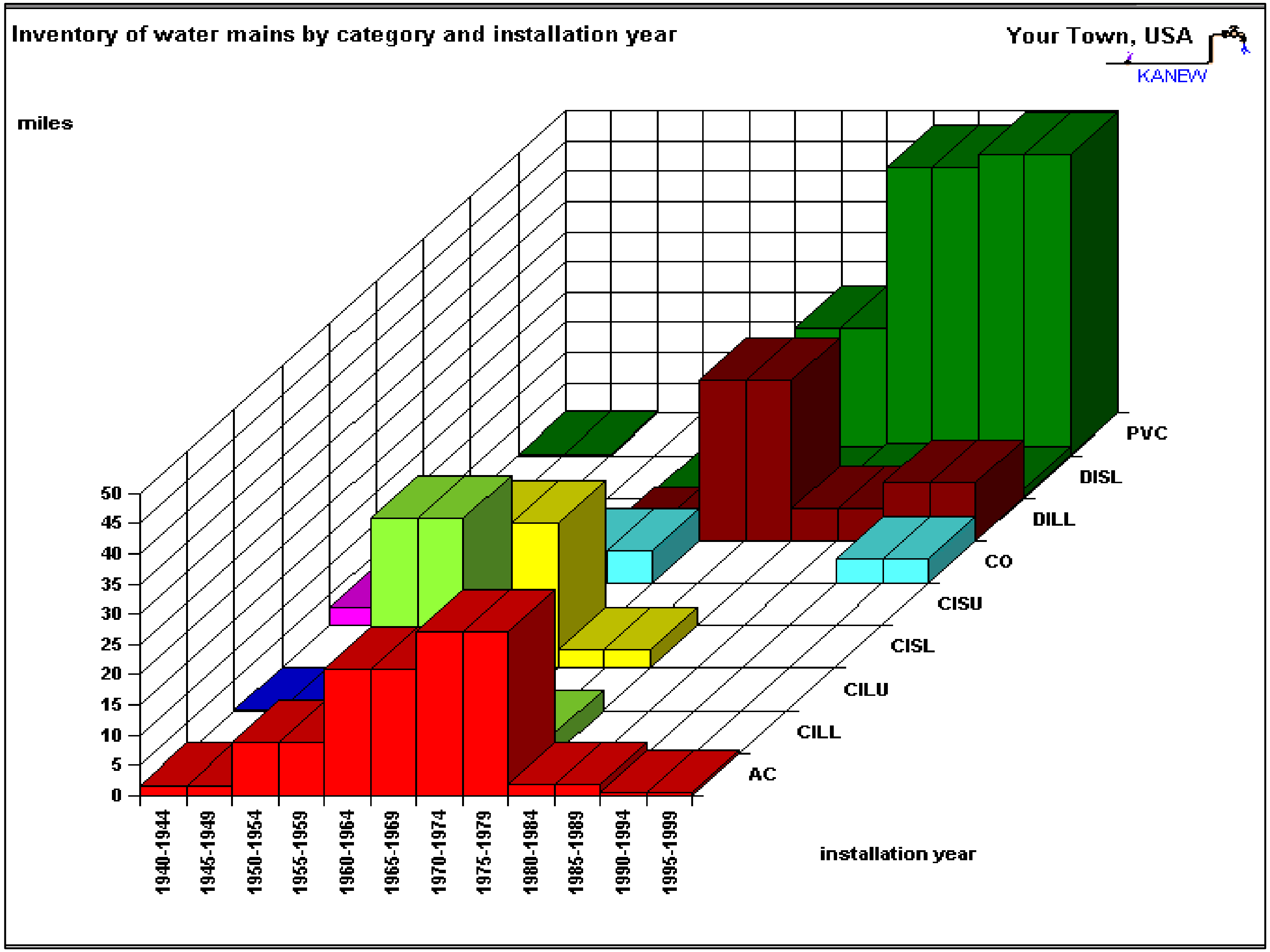
What Distinguishes EAMS from CMMS?



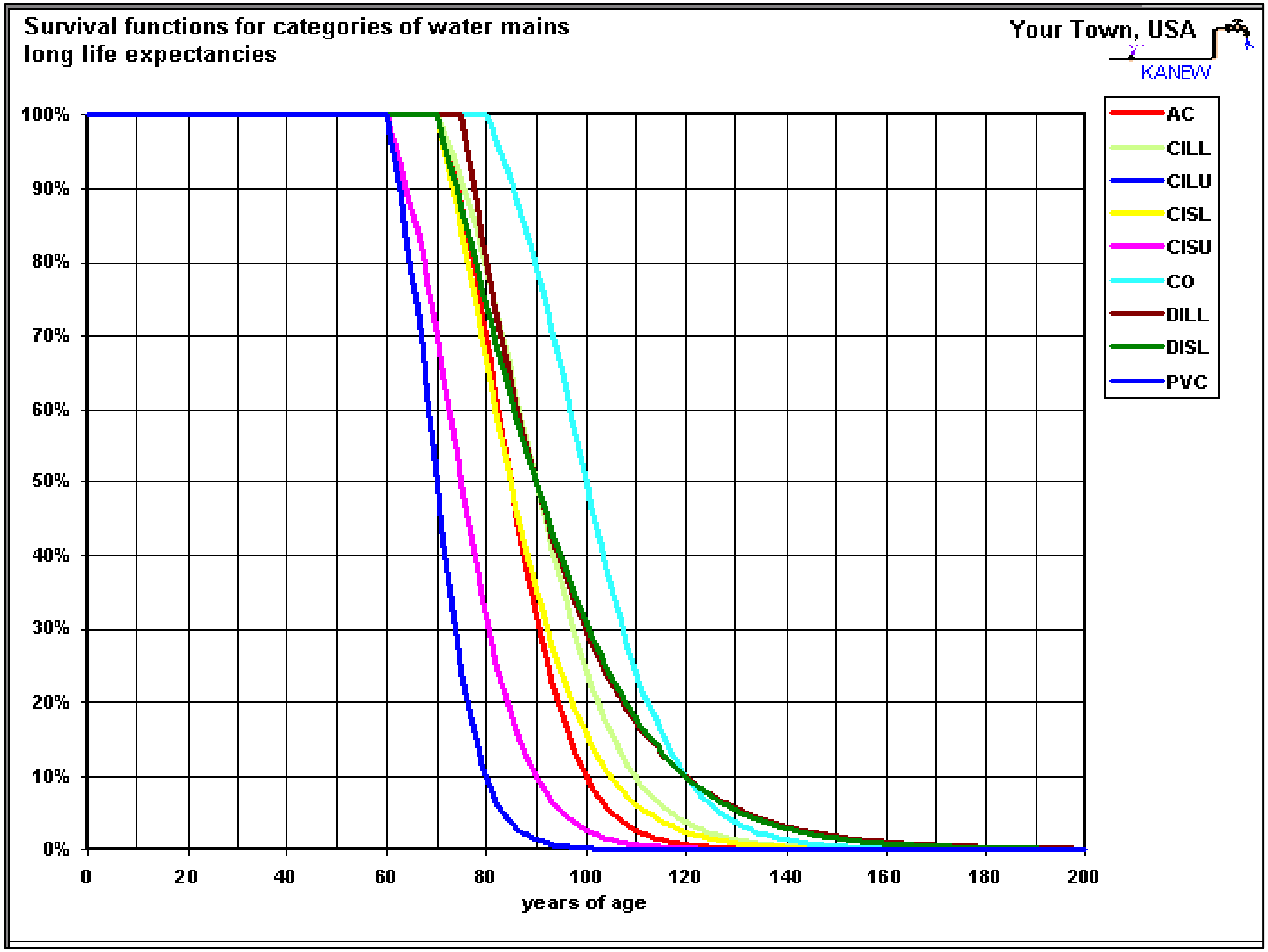
Focus is on the *maintenance work order* and maintenance performance for a defined period

Focus is on an *asset's performance* over its life cycle and on aggregate performance of asset groups

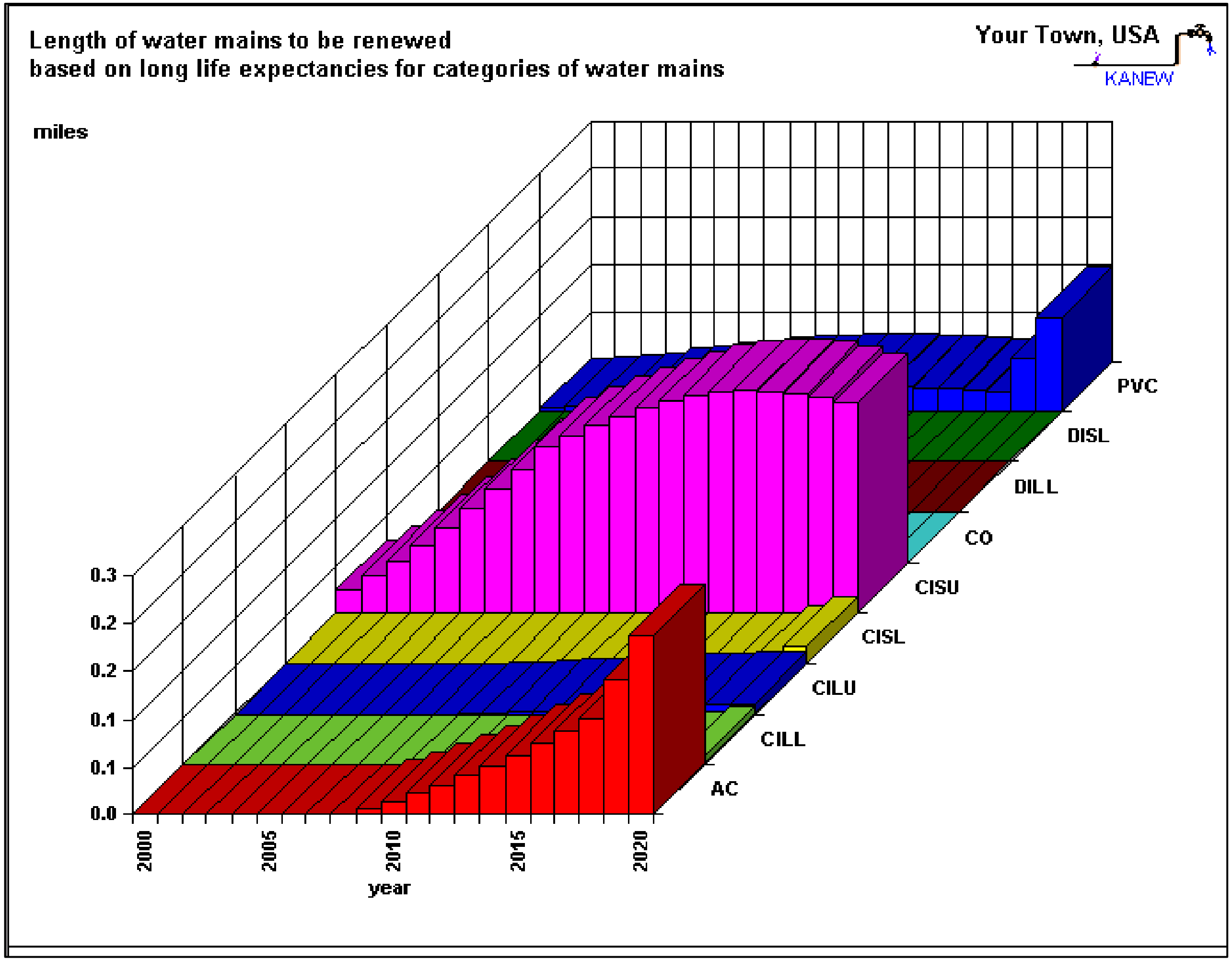
The asset portfolio view - 1



The asset portfolio view - 2



The asset portfolio view - 3

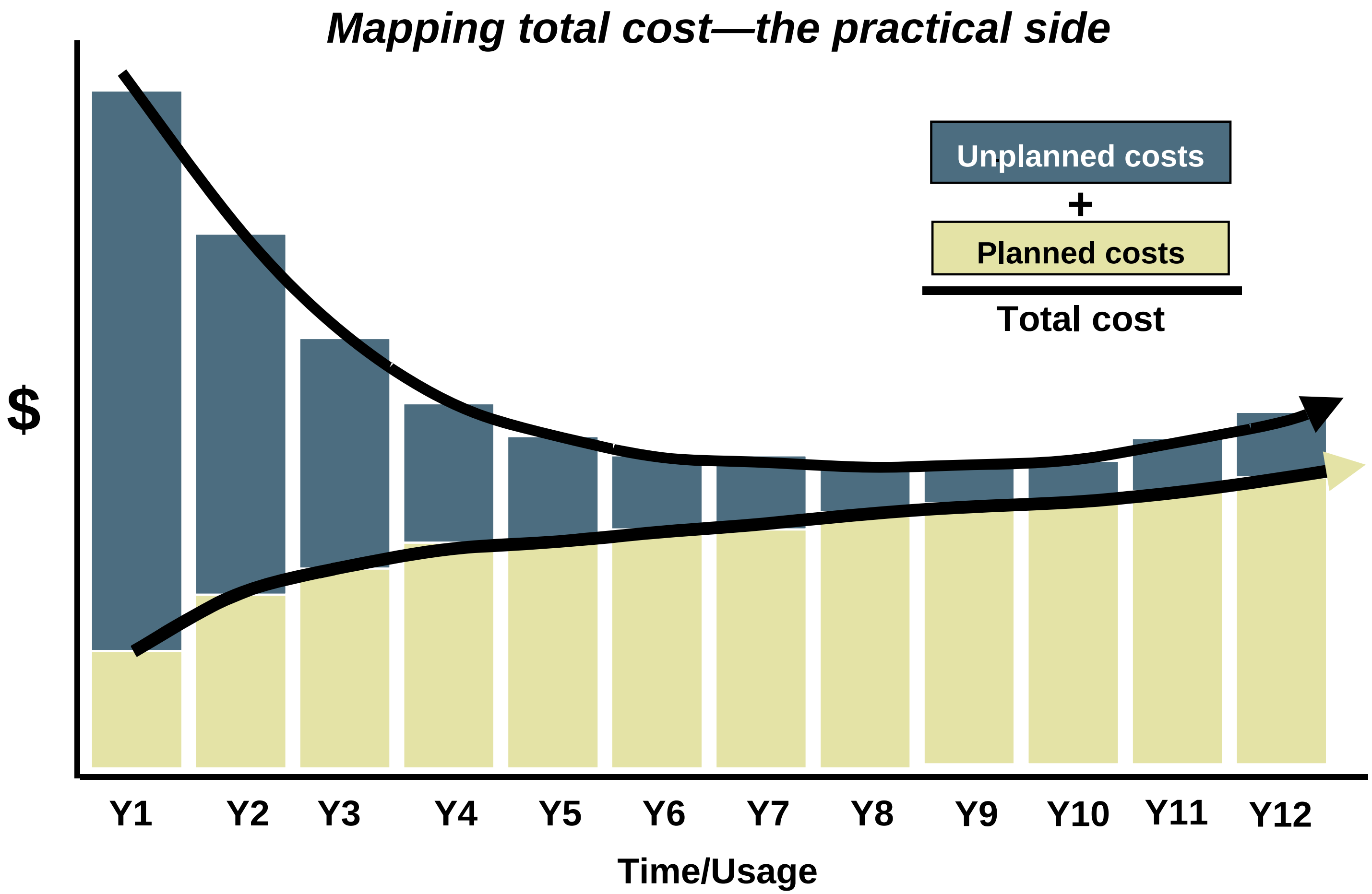


The Cost of Maintenance

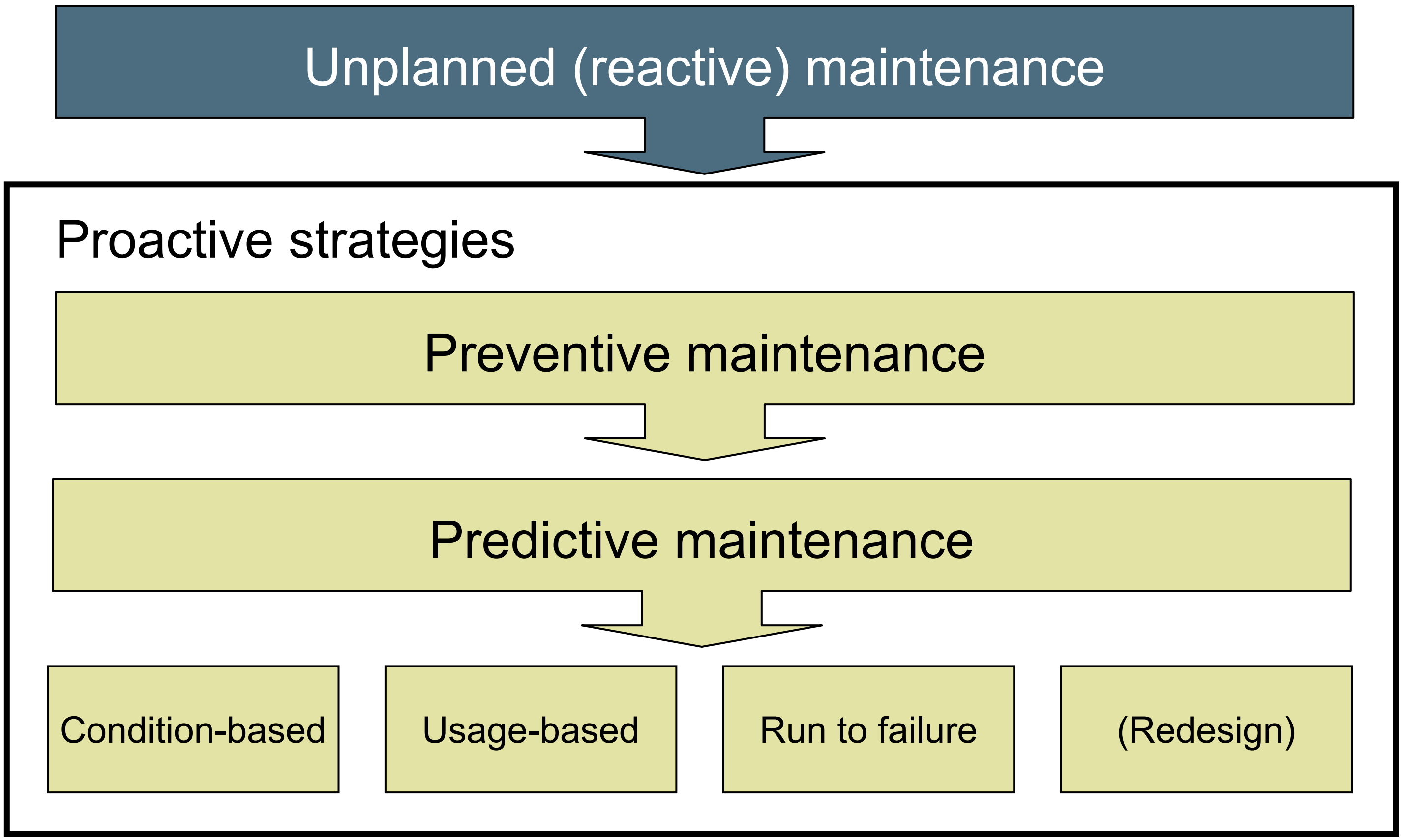
Rule of thumb

Roughly speaking, planned maintenance costs *one-third less* than unplanned maintenance for the same task

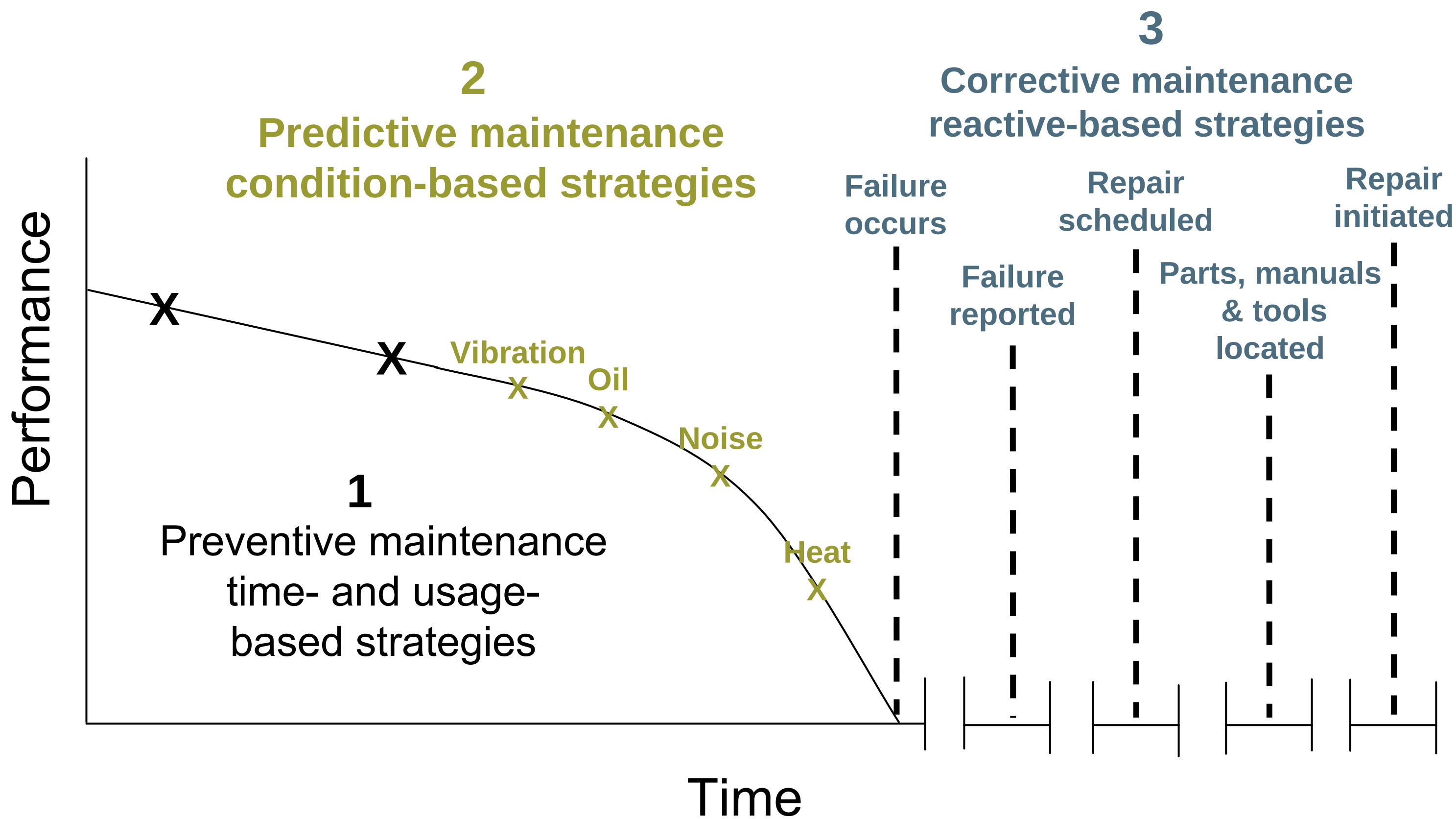
Transition to Planned Maintenance



Evolution of maintenance techniques



Fitting maintenance strategies to failure curve



Cost comparison strategies & tactics—the maintenance toolbox

Core strategies		
Total productive maintenance	Reliability centered maintenance	Zero breakdown maintenance

Operational tactics			
Design reliability analysis	Asset condition assessment	Early equipment management	Maintenance prevention
Accelerated deterioration elimination	Infrastructure, equip-ment, & component standardization	Commodity configuration management	Design for serviceability
Failure lead-time analysis	Demand criticality classification	Location failure analysis	Standardized failure codes

Total productive maintenance

- Embraces both asset design and maintenance
- Goal is to maximize Overall Equipment Effectiveness (OEE), where

    OEE = availability x performance efficiency x “first-time-through” quality

- Focuses on developing a comprehensive asset management plan for each asset for the life of the asset
- Ties maintenance objectives to the value chain (set-up time, lack of materials, poor quality, equipment functional failures, etc.)

Zero breakdown maintenance

Comprised of six core strategies

1. Eliminate continuing deterioration by establishing basic equipment conditions
2. Eliminate continuing deterioration by complying with conditions of use
3. Restore equipment to its optimal condition by restoring deterioration
4. Restore processes to their optimal condition by abolishing conditions that cause accelerated deterioration
5. Lengthen equipment lifetimes by correcting design weaknesses
6. Eliminate unexpected failures by improving operating and maintenance skills

Zero breakdown maintenance

Strategies are deployed in four steps

1. Reduce variation in failure intervals
2. Lengthen equipment life
3. Periodically restore deterioration
4. Predict equipment life from its condition

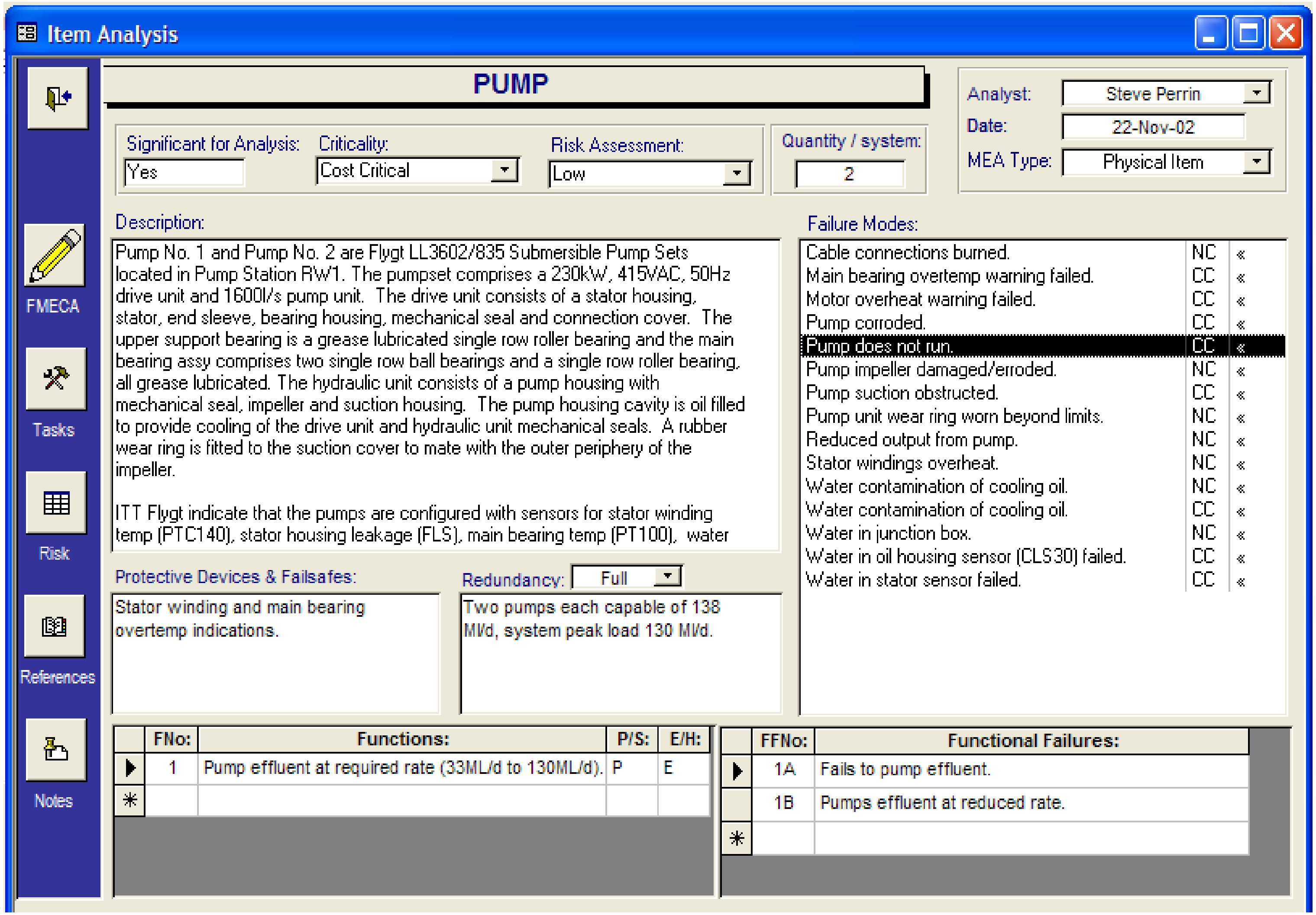
Reliability-centered maintenance—the seven fundamental questions

1. What are the functions and associated performance standards of the asset in its present operating context?
2. In what ways does it fail to fulfill its functions?
3. What causes each functional failure?
4. What happens *mechanically* when each failure occurs?
5. In what way does each failure matter?
6. What can be done to predict or prevent each failure?
7. What should be done if a suitable proactive task cannot be found?

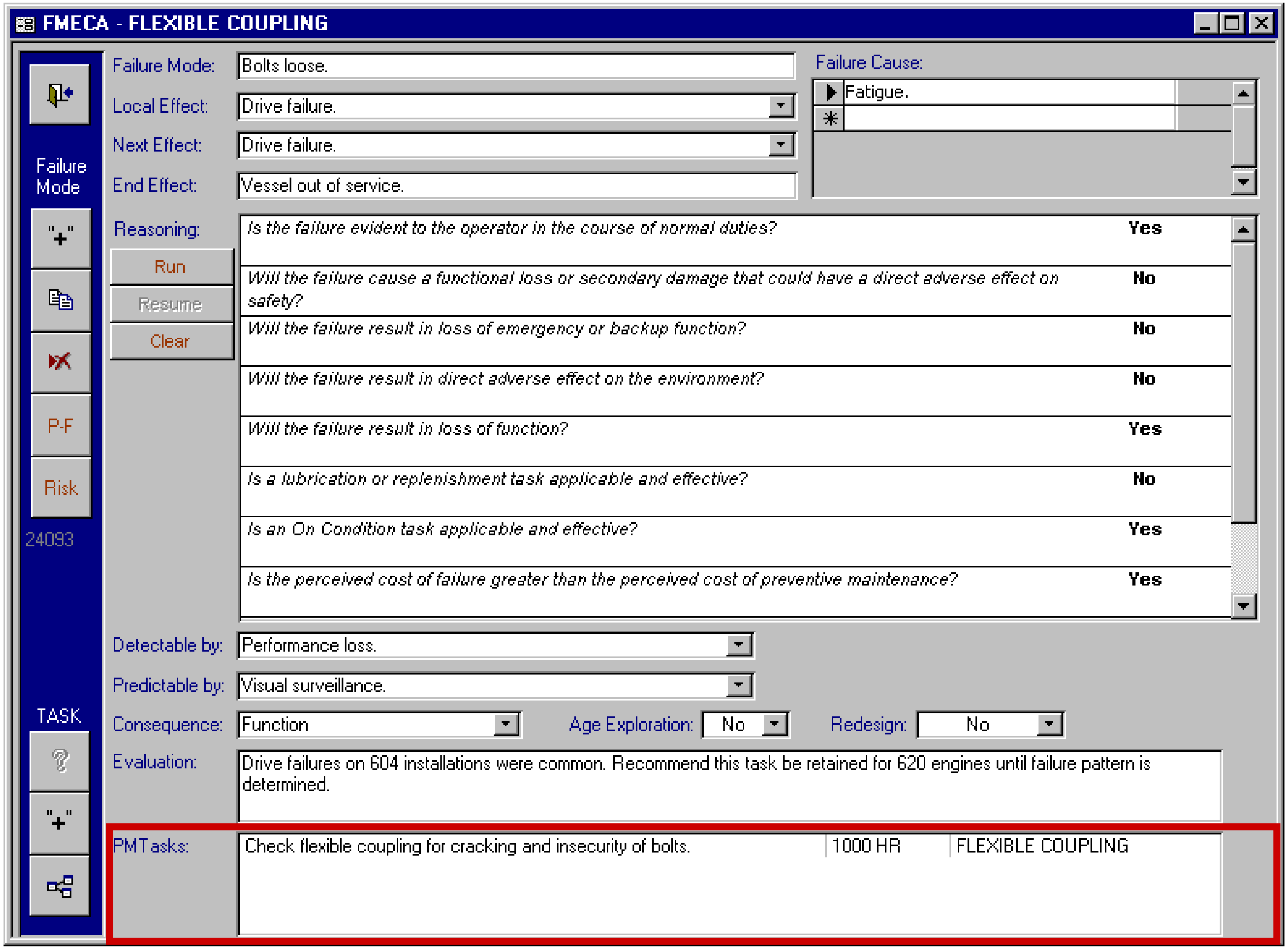
Techniques

- Function and performance standards
- Functional failures
- Failure modes
- Failure effects
- Failure consequences
- Proactive tasks

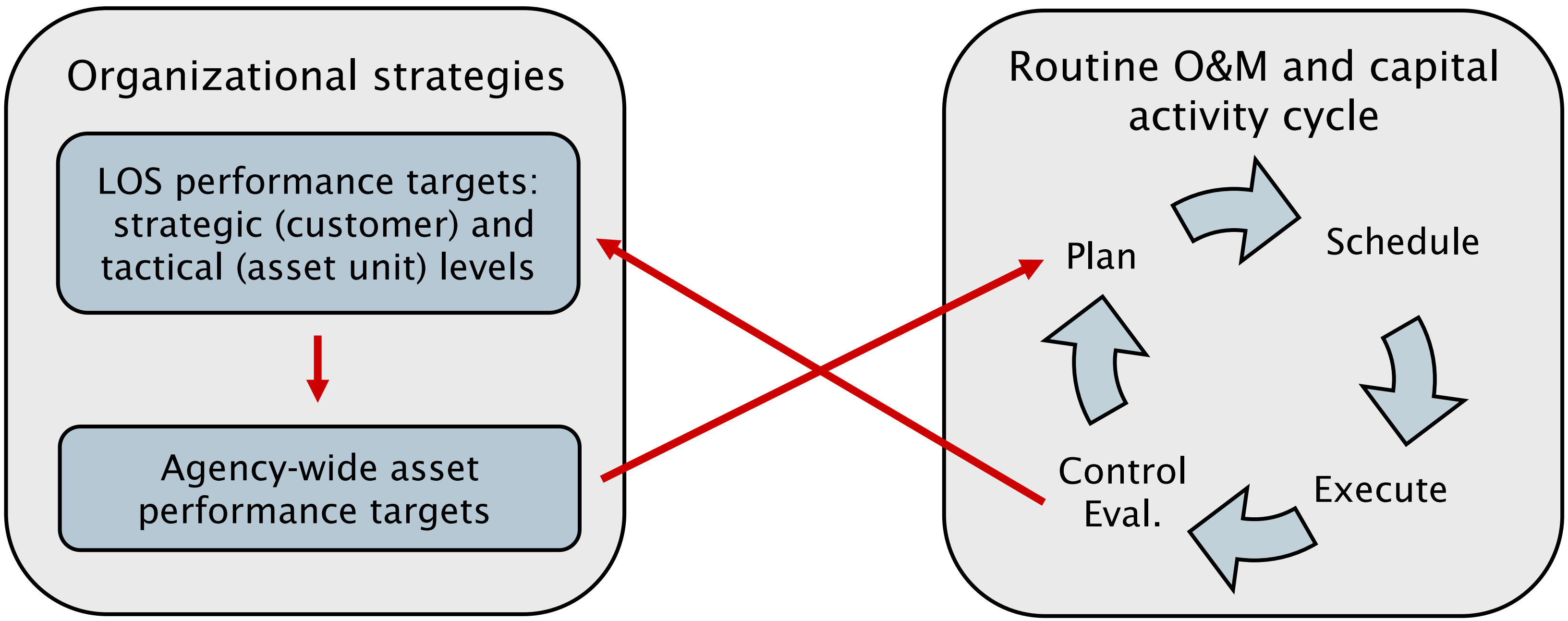
Intervention action—RCM



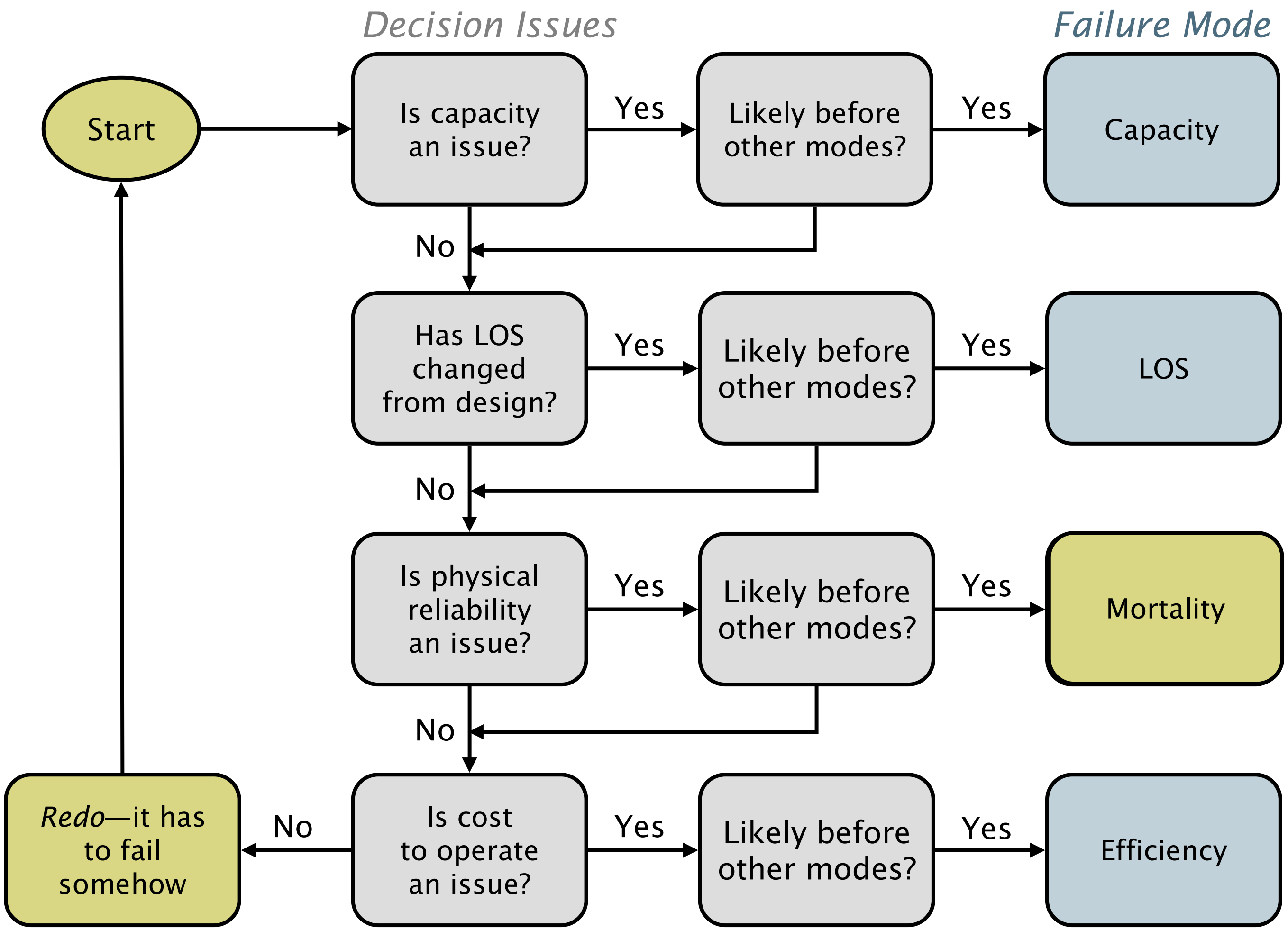
Intervention action—RCM, cont.



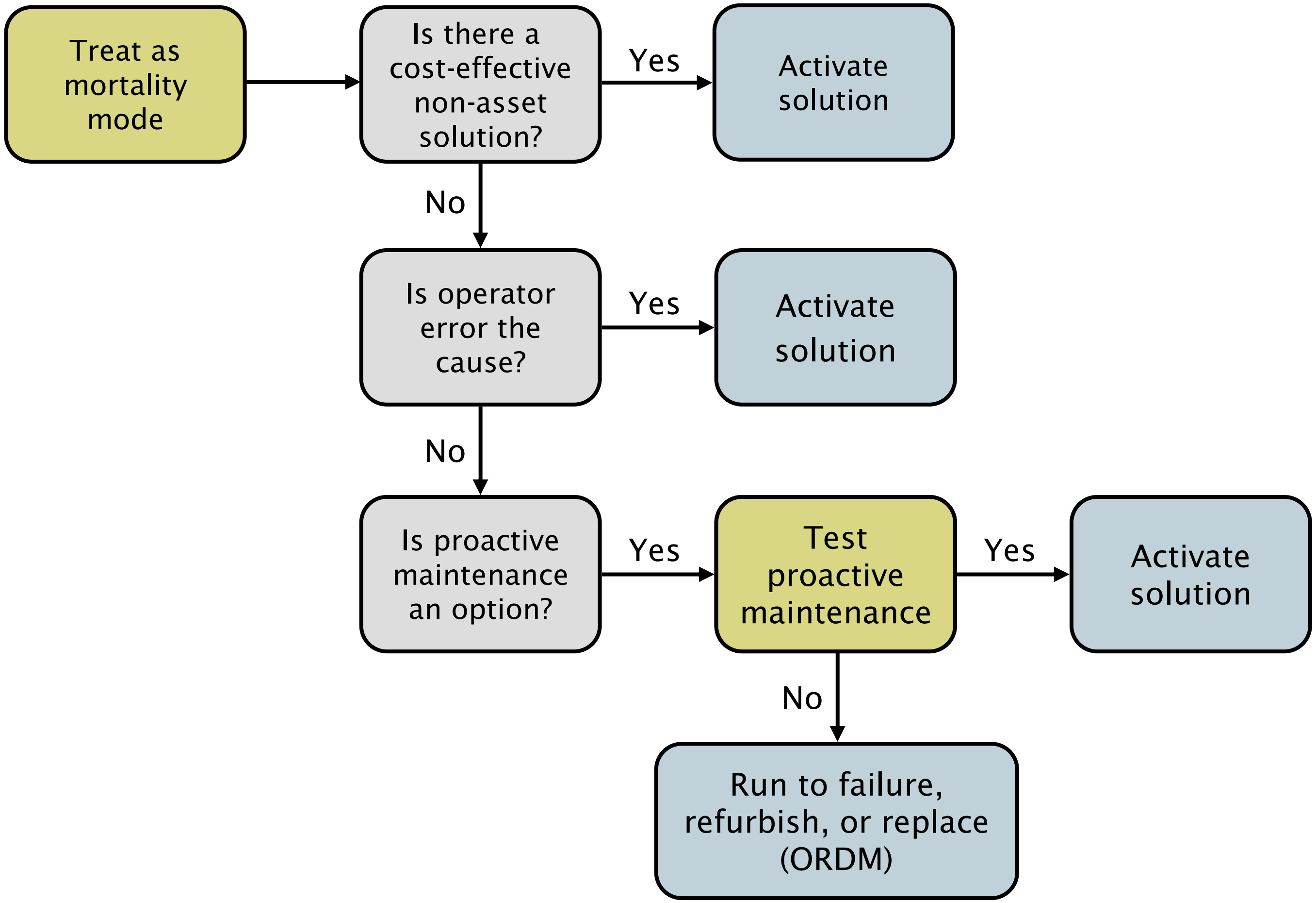
Alignment of routine O&M activities with organizational strategies



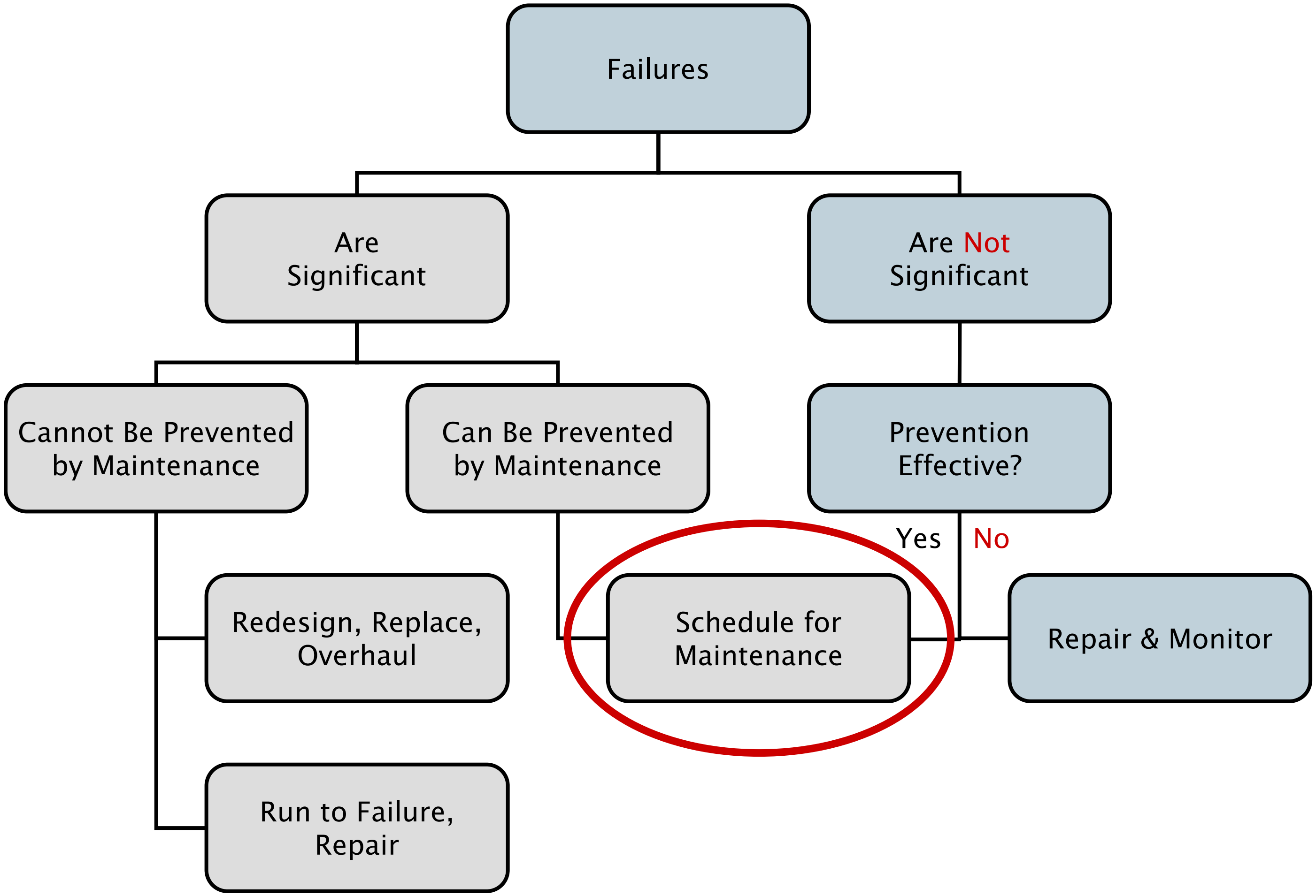
Using failure modes to determine probability of failure



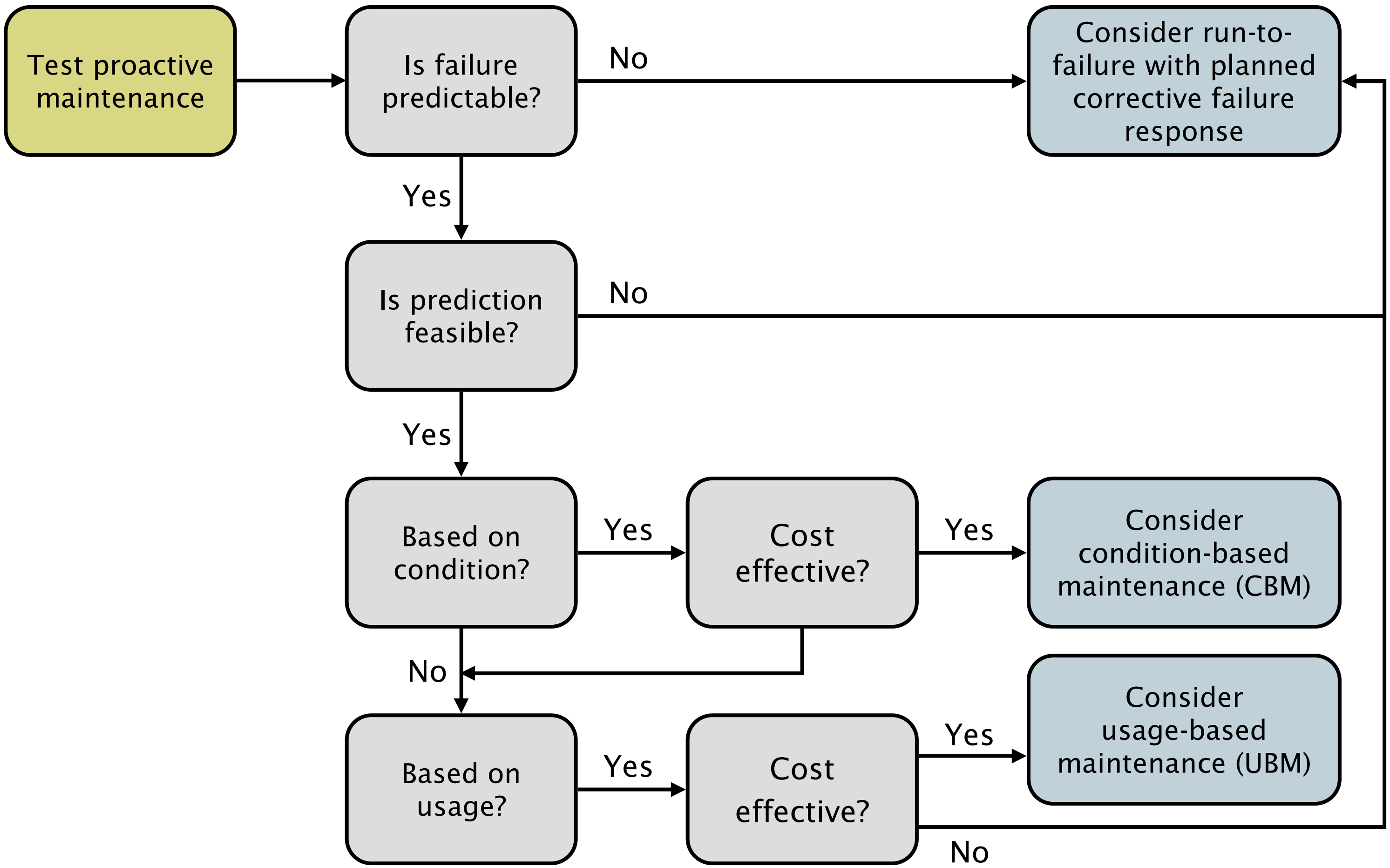
Tactical-level failure modes



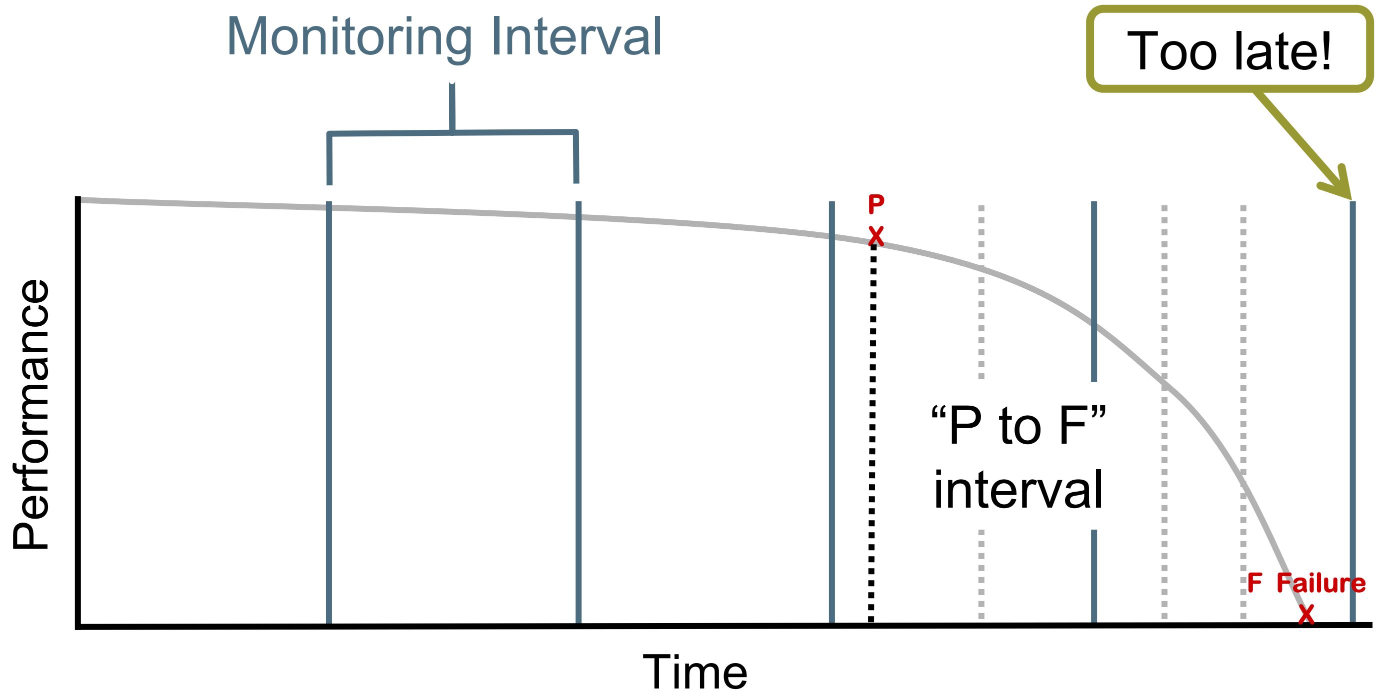
Failure mode-based management logic



Mortality failure mode: Determining appropriate maintenance tactics

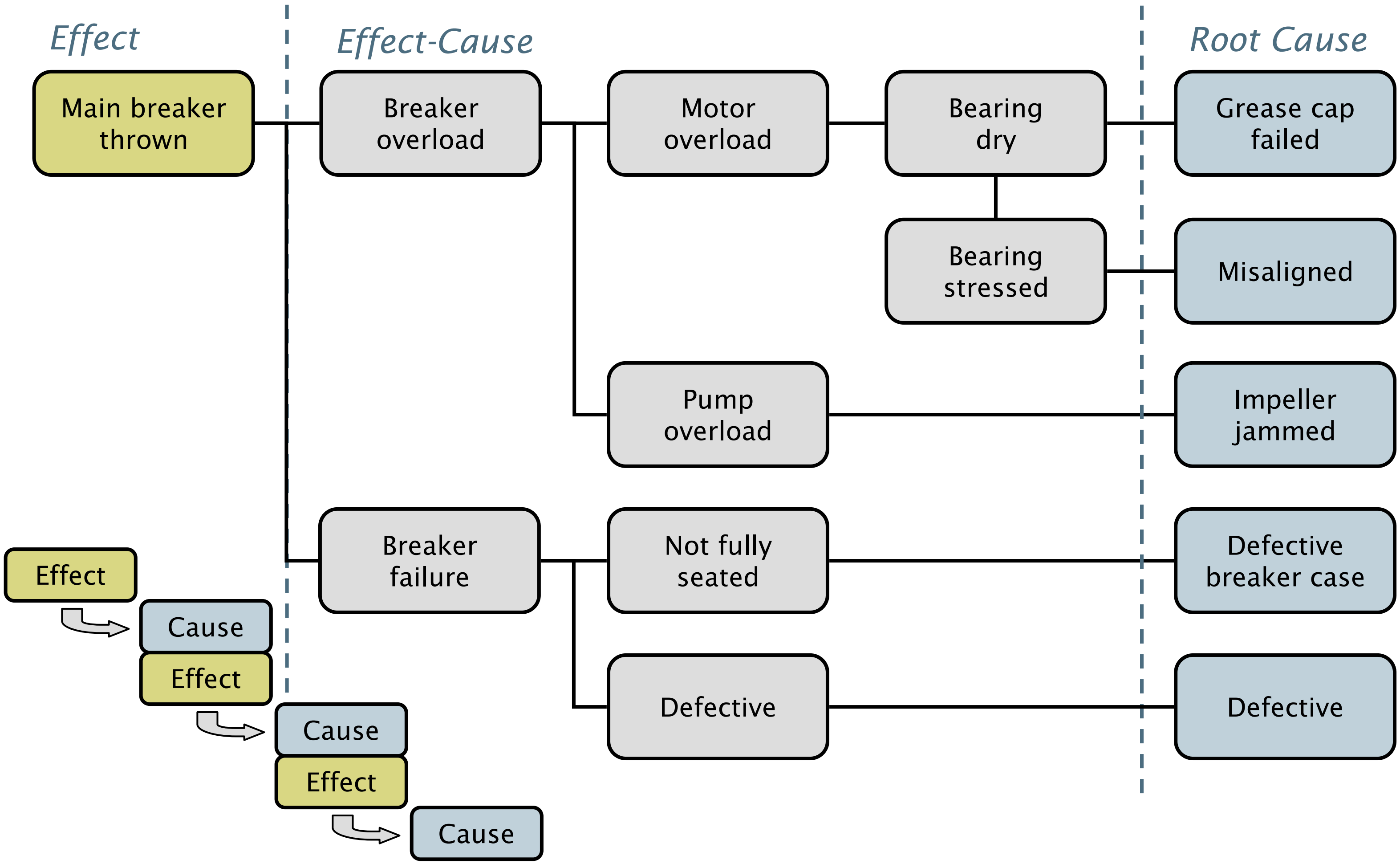


Predictive maintenance and the monitoring interval

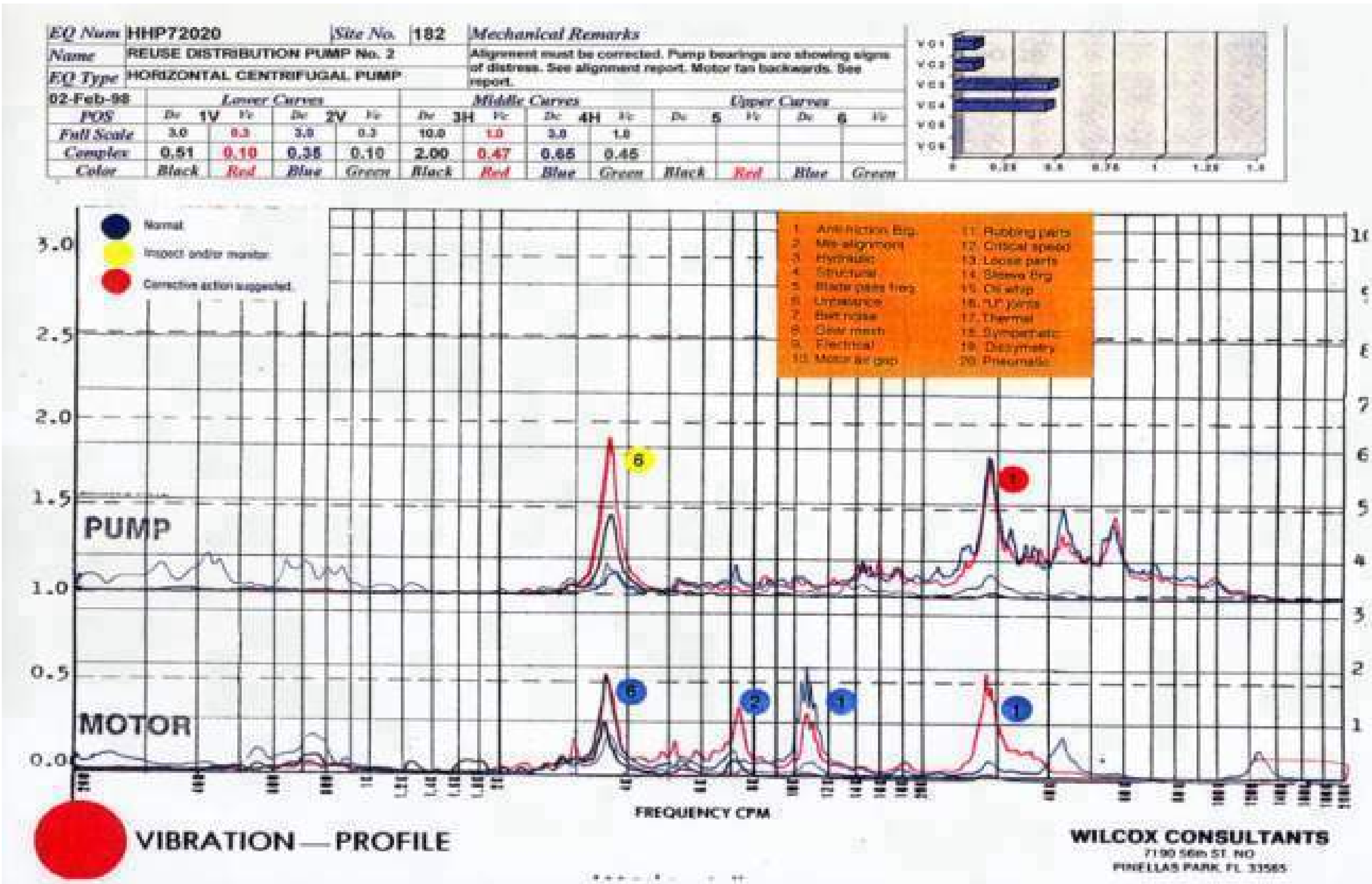


Can the progression of the failure be detected? Is there typically enough time to respond? Does consequence exceed cost of cure?

Cause and effect diagram—what to monitor



Condition-based maintenance: Vibration analysis



Power evaluation

Sample County - Waste Water Utilities Systems																	
Sewage Lift Stations - Electrical Report - Data as Recorded, June, 1998																	
	Voltage Line to Line			Amperage			Voltage Drops			Power Data				Horsepower and Load Percent			
Equip. Number	A to B	B to C	C to A	A	B	C	A	B	C	KVA	KVAR	KW	PF	Calc.	Rated	Percent	
20LS-RSP-002	244.0	243.0	244.0	24.2	23.7	24.3	0.09	0.08	0.09	9.7	6.9	6.8	90.0	9.1	15.00	60.7	
ABLS-RSP-001	474.0	473.0	475.0	24.1	25.1	25.7				17.5	2.8	17.2	98.7	23.1	25.00	92.4	
ABLS-RSP-002	474.0	474.0	475.0	27.5	26.7	29.1				16.8	3.2	16.5	98.6	24.8	25.00	99.2	
ABLS-RSP-003	474.0	475.0	475.0	25.4	25.8	29.5				17.8	2.9	17.6	98.7	23.6	25.00	94.4	
BELS-RSP-001	239.0	240.0	242.0	59.8	52.6	65.7	0.19	0.19	0.18	23.9	12.7	20.3	84.9	27.2	25.00	108.8	
BELS-RSP-002	240.0	242.0	240.0	50.5	51.3	55.4	0.16	0.16	0.18	21.5	13.6	16.7	77.6	22.4	25.00	89.6	
BGLS-RSP-001	242.0	241.0	242.0	8.5	8.6	8.8	0.30	0.30	0.36	3.6	2.4	2.7	74.5	3.6	3.00	120.0	
BGLS-RSP-002	242.0	241.0	242.0	9.4	9.3	9.6	0.24	0.18	0.17	3.9	2.1	3.3	84.2	4.4	3.00	146.7	
BLLS-RSP-001	479.0	475.0	468.0	3.9	3.8	3.9	0.08	0.08	0.07	3.0	2.0	2.3	75.3	3.1	2.00	155.0	
BLLS-RSP-002	482.0	483.0	485.0	4.0	3.9	4.0	0.08	0.06	0.13	3.1	2.1	2.3	73.9	3.1	2.00	155.0	
CMLS-RSP-001	457.0	456.0	456.0	6.6	6.6	7.2	0.40	0.40	0.42	5.1	3.6	3.7	71.3	5.0	7.50	66.7	
CMLS-RSP-002	457.0	458.0	458.0	6.0	6.0	6.1	0.27	0.27	0.63	4.7	3.8	2.7	58.0	3.6	7.50	48.0	
DWLS-RSP-001	486.0	485.0	486.0	22.1	22.9	24.0	0.14	0.21	0.14	19.0	10.9	15.6	82.0	20.9	20.00	104.5	
DWLS-RSP-002	485.0	486.0	486.0	21.3	22.0	22.8	0.16	0.14	0.15	18.3	10.7	14.8	81.1	19.8	20.00	99.0	
FDLS-RSP-001	239.0	239.0	239.0	21.1	22.1	22.8	0.21	0.28	0.20	9.0	6.6	6.1	68.2	8.2	10.00	82.0	
FDLS-RSP-002	240.0	239.0	240.0	23.9	24.0	25.6	0.26	0.26	0.31	10.0	7.0	7.1	70.9	9.5	10.00	95.0	
FRLS-RSP-001	212.0	213.0	215.0	4.9	5.4	5.9	0.23	0.22	0.26	2.0	1.5	1.3	66.5	1.7	2.00	85.0	
FRLS-RSP-002	212.0	213.0	215.0	5.2	5.6	6.1	0.25	0.25	0.27	2.1	1.5	1.4	70.0	1.9	2.00	95.0	
FSLS-RSP-001	239.0	240.0	240.0	33.7	36.8	42.7	0.14	0.14	0.13	14.8	10.3	10.6	71.7	14.2	15.00	94.7	
FSLS-RSP-002	239.0	239.0	240.0	31.4	34.7	39.8	0.17	0.18	0.19	13.9	10.7	8.9	63.9	11.9	15.00	79.3	
H6LS-RSP-001	244.0	242.0	242.0	9.2	8.8	9.5	0.62	0.79	0.73	3.8	2.5	2.9	74.7	3.9	3.00	130.0	
H6LS-RSP-002	242.0	242.0	241.0	10.2	9.5	10.0	0.49	0.81	0.60	4.1	2.9	2.9	70.8	3.9	3.00	130.0	
HCLS-RSP-001	242.0	242.0	243.0	28.4	27.1	26.0	0.12	0.10	0.12	11.2	9.0	6.7	59.3	9.0	15.00	60.0	
HCLS-RSP-002	243.0	242.0	243.0	28.3	26.9	25.6	0.12	0.11	0.12	11.2	8.6	7.1	63.6	9.5	15.00	63.3	
HKLS-RSP-001	241.0	241.0	242.0	60.3	60.1	38.2	0.46	0.30	0.72	27.1	20.6	17.7	65.1	23.7	40.00	59.3	
HKLS-RSP-002	240.0	241.0	241.0	62.4	63.2	66.0	0.23	0.36	0.66	26.6	15.9	21.3	80.2	28.6	40.00	71.5	
HSLS-RSP-001	208.0	206.0	208.0	240.3	26.2	28.1	0.19	0.19	0.28	9.0	5.8	6.9	76.5	9.2	10.00	92.0	
HSLS-RSP-002	208.0	206.0	208.0	24.1	26.4	27.7	0.17	0.19	0.20	9.0	5.7	6.7	77.4	9.0	10.00	90.0	
JHLS-RSP-001	244.0	243.0	243.0	50.9	52.4	51.6	0.21	0.65	0.19	21.4	15.4	14.9	69.6	20.0			
JHLS-RSP-002	245.0	244.0	245.0	44.1	42.9	45.1	0.38	0.54	0.32	18.4	12.7	13.4	72.7	18.0			
MWLS-RSP-001	241.0	240.0	241.0	11.0	11.6	12.4	0.19	0.13	0.14	4.7	2.5	4.0	84.8	5.4	7.50	72.0	

Prepared by Wilcox Consulting Inc. - Madeira Beach Office - 11/8/00

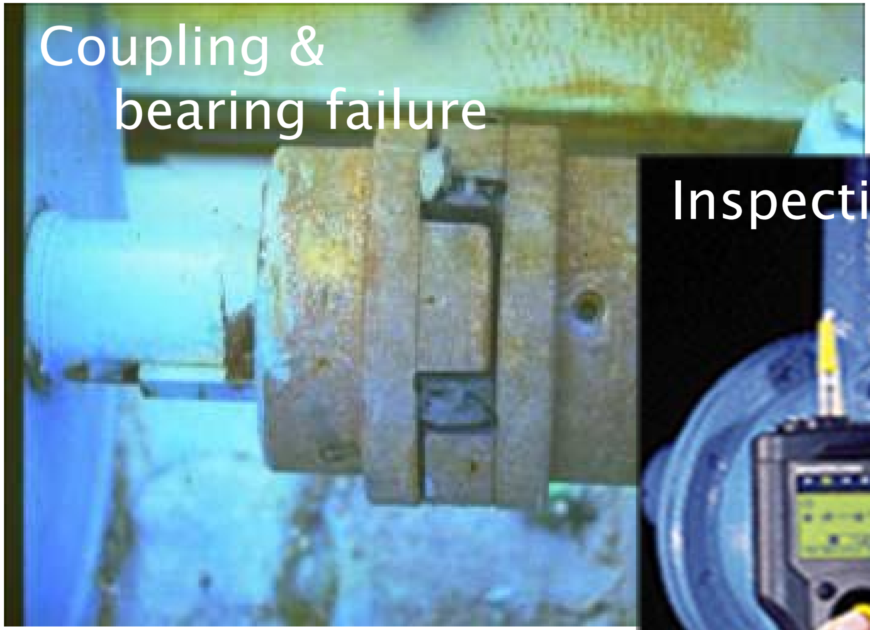
Page 1

Most condition indicators are not visible to the unaided eye

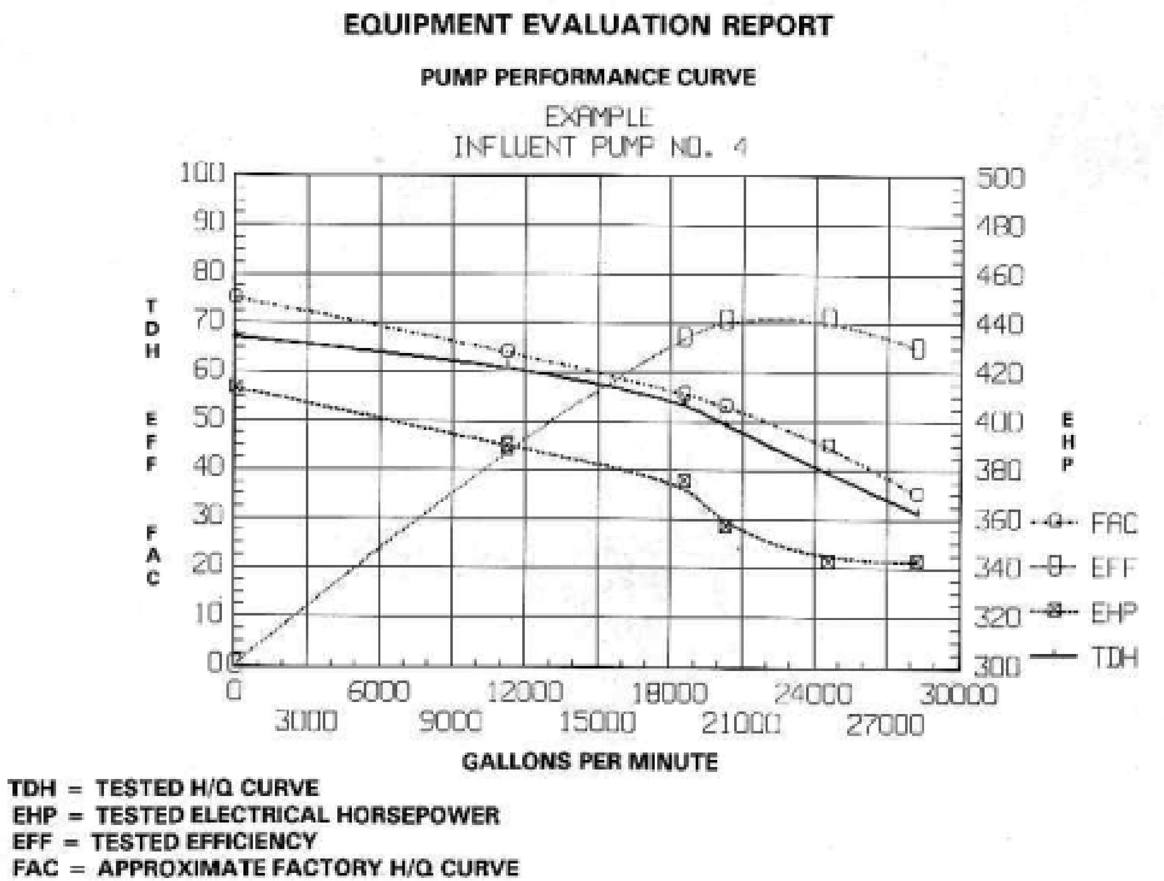
Visual inspection

Infrared view

Alignment of inspection and correction data

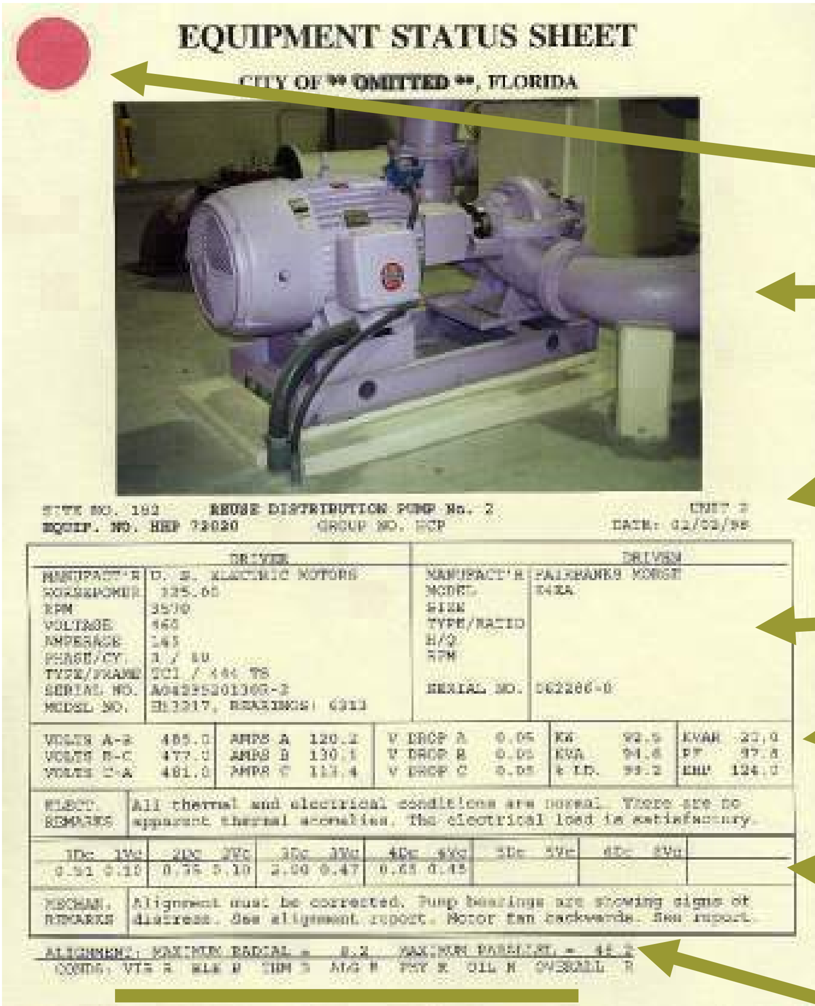


Baseline machine performance tests



Baseline at handover sets life cycle benchmark. Conforms to factory test curves?

Status sheet (summary)



EQUIPMENT STATUS SHEET

CITY OF ** OMITTED **, FLORIDA

SITE NO. 182 REUSE DISTRIBUTION PUMP No. 2 UNIT 2

EQUIP. NO. HEP 72020 GROUP NO. HCP DATE: 02/02/98

DRIVER		DRIVEN	
MANUFACT'R	U. S. ELECTRIC MOTORS	MANUFACT'R	FAIRBANKS MORSE
HORSEPOWER	125.00	MODEL	5424A
RPM	3570	SIZE	
VOLTAGE	460	TYPE/RATIO	
AMPERAGE	143	H/Q	
PHASE/CY	3 / 60	RPM	
TYPE/FRAME	TCI / 444 TS		
SERIAL NO.	A04225201305-2	SERIAL NO.	162286-0
MODEL NO.	H13217, BEARINGS: 6313		

VOLTS A-B	485.0	AMPS A	120.2	V DROP A	0.06	KW	92.5	KVAR	20.0
VOLTS B-C	477.0	AMPS B	130.1	V DROP B	0.05	KVA	94.6	PF	97.8
VOLTS C-A	481.0	AMPS C	113.4	V DROP C	0.08	% LD.	99.2	EHP	124.0

ELECT. REMARKS: All thermal and electrical conditions are normal. There are no apparent thermal anomalies. The electrical load is satisfactory.

1Dc	1Vc	2Dc	2Vc	3Dc	3Vc	4Dc	4Vc	5Dc	5Vc	6Dc	6Vc
0.91	0.10	0.75	5.10	2.00	0.47	0.65	0.45				

MECHAN. REMARKS: Alignment must be corrected. Pump bearings are showing signs of distress. See alignment report. Motor fan backwards. See report.

ALIGNMENT: MAXIMUM RADIAL = 8.2 MAXIMUM PARALLEL = 41.2

CONDS: VTS R ELE R THM R M/G R PMY R OIL R OVERALL R

Overall condition

Picture of machine

Description

All nameplate data

Electrical data

Vibration data

Alignment data

Equipment status list

Severity color code

EQUIPMENT SUMMARY REPORT - STATUS LIST

June, 1998

Equipment Number LOCEQ	Site Number SITENO	Overall OACC	Vibration VIBC	Electrical ELEC	Thermo-graphy THRC	Alignment ALGC	Physical PHYC	Oil OILC
20LS-RSP-001	113A	O	N	N	N	N	R	N
20LS-RSP-002	113B	Y	Y	B	B	N	B	N
ABLS-RSP-001	101A	Y	B	B	B	N	B	N
ABLS-RSP-002	101B	Y	Y	B	B	N	B	N
ABLS-RSP-003	101C	Y	B	N	N	N	R	N
ABTP-ADU-001	201	B	B	Y	B	N	B	B
ABTP-ADU-002	202	Y	N	N	N	N	B	B
ABTP-ADU-003	203	B	N	N	N	N	B	B
ABTP-ADU-004	204	R	N	N	N	N	B	B
ABTP-BC1-001	205	R	N	N	N	N	B	R
ABTP-BC1-002	206	R	N	B	B	N	B	R
ABTP-BC1-002	207	R	B	B	B	N	B	R
ABTP-MAC-001	225	N	B	B	B	N	B	N
ABTP-PFP-001	226	N	B	B	B	N	B	N
ABTP-SFP-001	223	N	N	N	N	N	N	N
ABTP-SFP-002	227	N	N	Y	B	N	Y	N
ABTP-SFP-002	224	N	R	R	B	N	R	N
ABTP-TBF-001	211	N	N	B	B	N	B	N
ABTP-TBF-002	212	N	N	B	B	N	B	N
ABTP-TBF-003	213	N	B	B	Y	N	B	N
ABTP-TBF-004	214	N	N	B	B	N	B	N
ABTP-TBF-005	215	N	Y	Y	B	N	Y	N
ABTP-TBF-006	216	N	N	Y	B	N	Y	N
ABTP-THK-001	220	R	N	N	N	N	N	R
ABTP-THK-002	221	B	B	B	B	N	B	N

Failure codes

- Use cause-effect diagrams to create codes
- Define codes by class of asset
- Use “drop-down” list

Failure Code

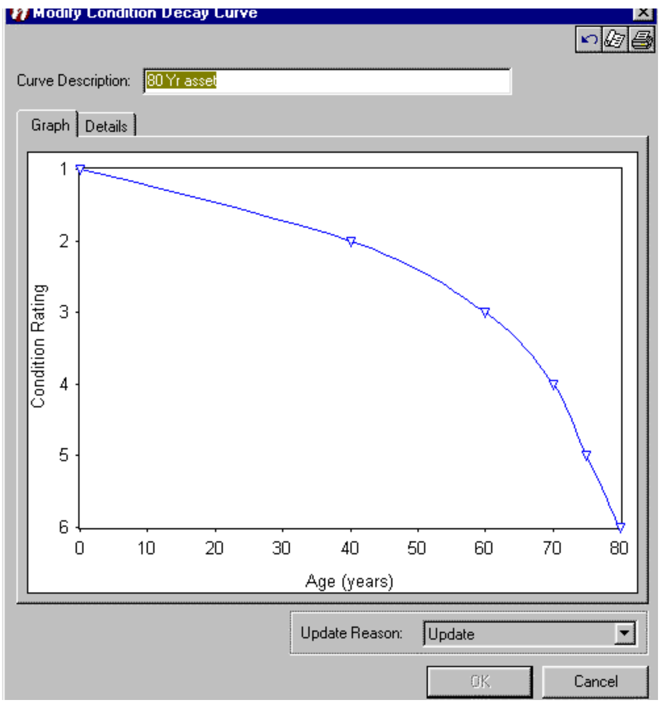
- Coupling failure
- Lube fault
- Misaligned
- Operator error
- Overloaded
- Water damage
- Worn

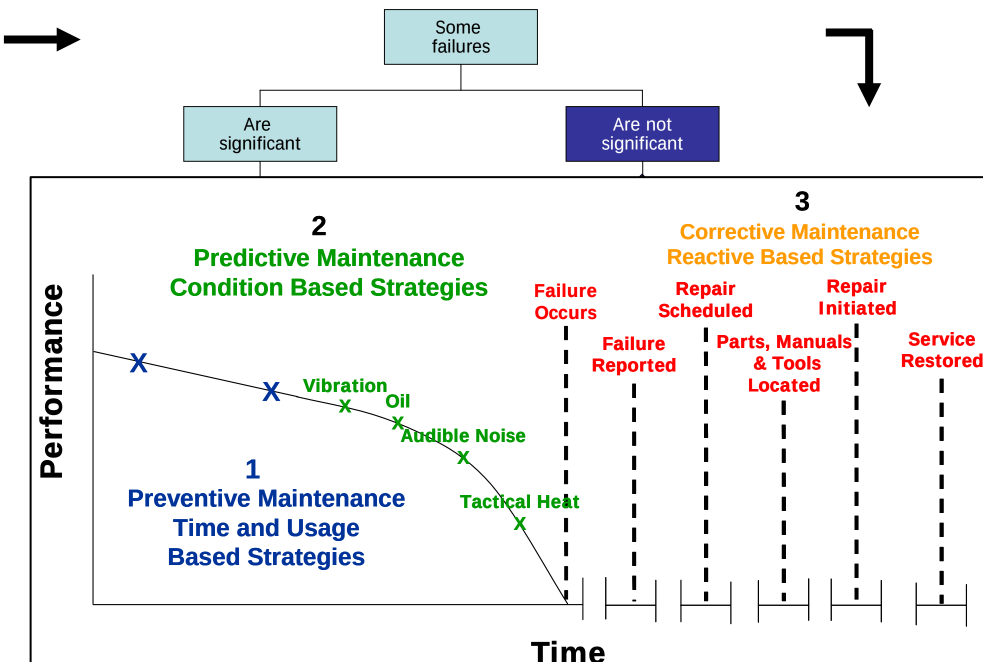
Condition-based maintenance

"Nameplate" Data

+

Vibration Signature	Sonic Signature	Thermal Signature	Electrical Signature	Performance Signature	Oil Residue Signature	Electro-magnetic Signature





Toward a maintenance strategy business case

Table 6.6
Mitigation Strategies: Reuse Scheme Only Failure Modes

	Maintenance Scenario A		**Maintenance Scenario B**		**Maintenance Scenario C**	
Maintenance Budget	Maintenance Budget $15,000		Maintenance Budget $7,000		Maintenance Budget $3,500	
Probability Improvement cause by maintenance	0.5 Reduction		Same Probability		1.3 Increase	
System / sub-system / component	*Improved Probability of Failure*	*Business Risk Exposure ($)*	*Improved Probability of Failure*	*Business Risk Exposure ($)*	*Improved Probability of Failure*	*Business Risk Exposure ($)*
Delivery Channel	0.010	$ 302	0.010	$ 302	0.010	$ 302
Pump Station						
1 pump fails	0.150	$ 648	0.300	$ 1,296	0.390	$ 1,685
2 pumps fail	0.050	$ 684	0.100	$ 1,368	0.130	$ 1,778
3 pumps fail	0.025	$ 761	0.050	$ 1,523	0.065	$ 1,980
All pumps fail	0.005	$ 302	0.010	$ 605	0.013	$ 786
Control System Power supply / sub-station	0.050	$ 1,512	0.050	$ 1,512	0.050	$ 1,512
Rising Main						
Pressure or pipe deflection	0.030	$ 907	0.030	$ 907	0.030	$ 907
Adjacent construction work	0.050	$ 1,512	0.050	$ 1,512	0.050	$ 1,512
Massive earth movement	0.050	$ 2,268	0.050	$ 2,268	0.050	$ 2,268
Ground movement	0.050	$ 2,268	0.050	$ 2,268	0.050	$ 2,268
HOR Storage						
HORS structure	0.050	$ 1,368	0.050	$ 1,368	0.050	$ 1,368
Variable Gate - Outlet 5W	0.050	$ 342	0.100	$ 684	0.130	$ 889
Variable Gate - Outlet to eastern carrier	0.050	$ 342	0.100	$ 684	0.130	$ 889
Penstocks - Actuator Fail	0.050	$ 342	0.100	$ 684	0.130	$ 889
Penstocks - Manual Overide	0.050	$ 342	0.100	$ 684	0.130	$ 889
External Factors Power Failure	0.200	$ 3,024	0.200	$ 3,024	0.200	$ 3,024
Total		$ 16,925		$ 20,689		$ 22,947
Sum of Maximum Value		$ 8,474		$ 8,485		$ 8,942

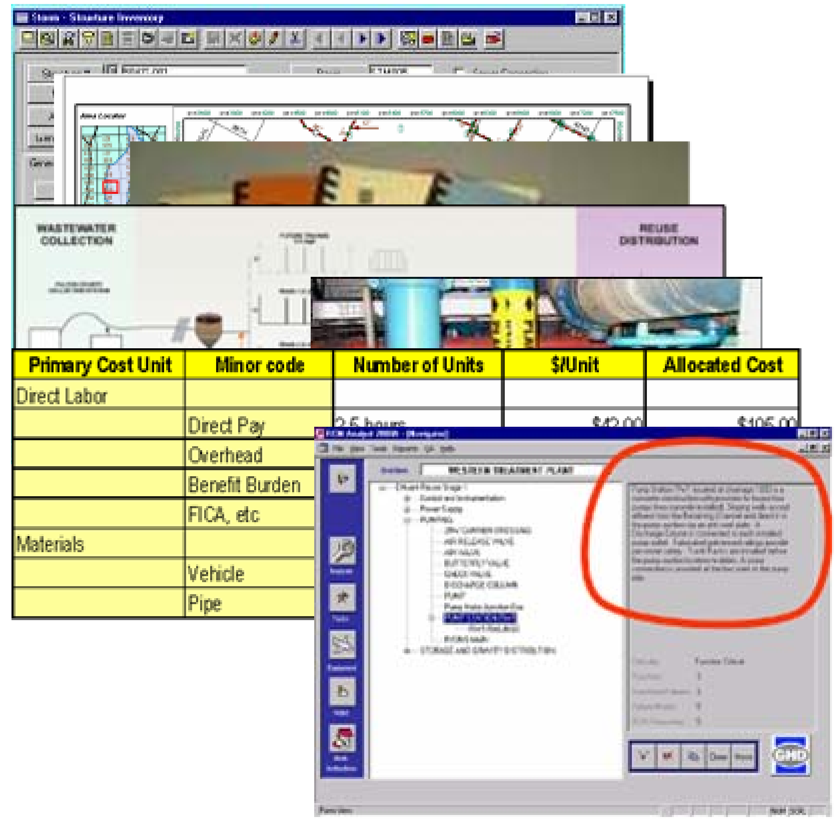
Conclusion

Justifiable maintenance between $1,500 and $3,500 per annum.

Major components of asset data

Used to *create an asset ID*…

- Physical attributes
- Geo-reference
- O&M manuals
- Drawings and photos
- Life cycle costs
- Knowledge and strategy



Tying together failure, reliability, and design

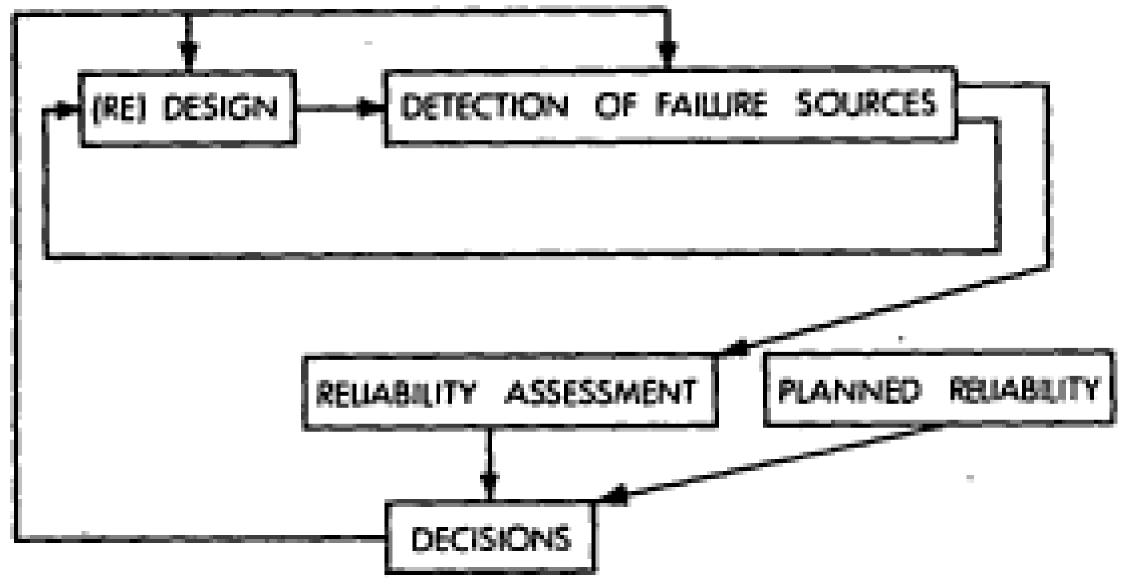
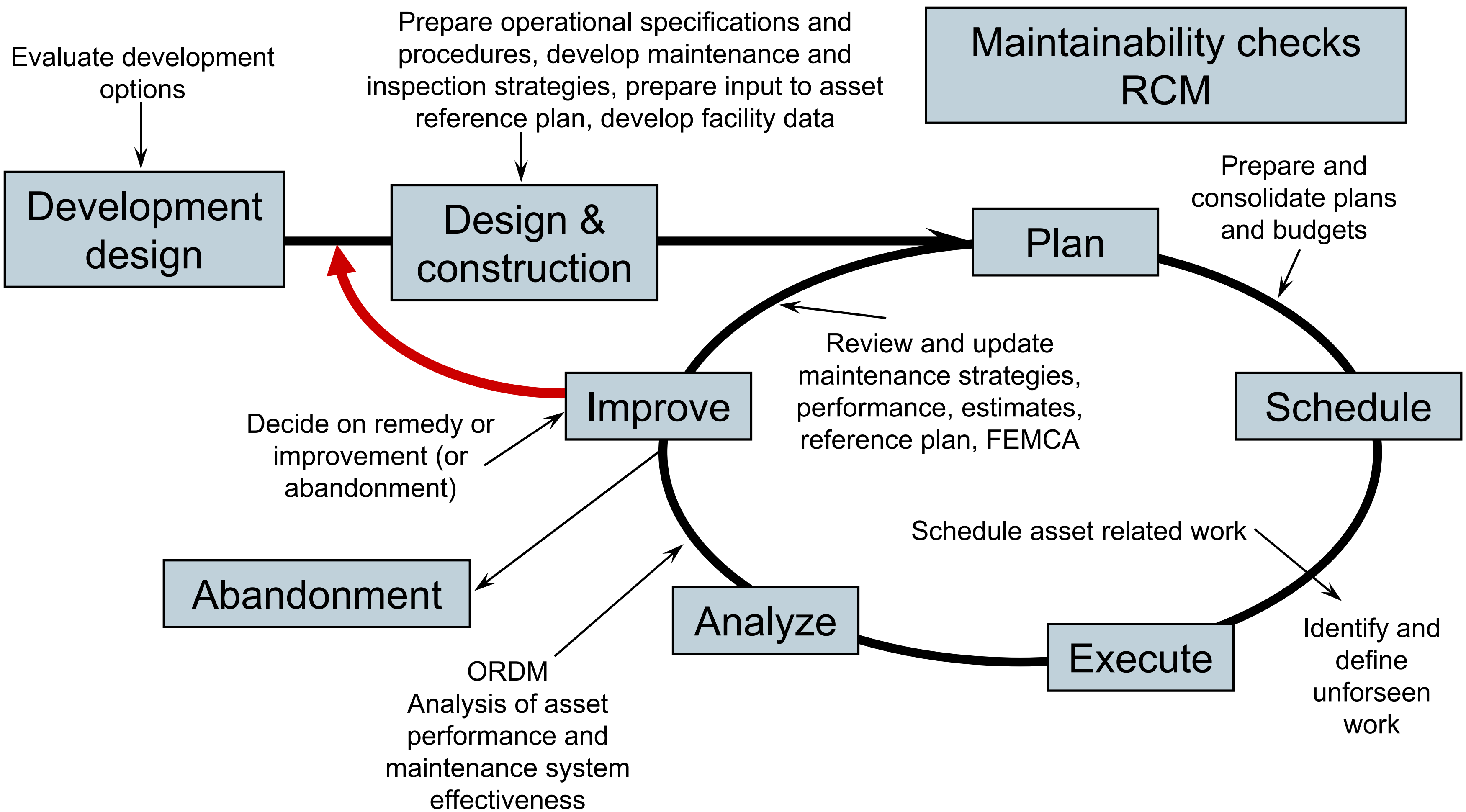


Figure 4.2 Reliability Growth Management Model (Assessment).

Military Handbook 189, Reliability Growth Management 1981

Linking maintenance and design



Key points from this session

Given my system, what are my best O&M strategies?

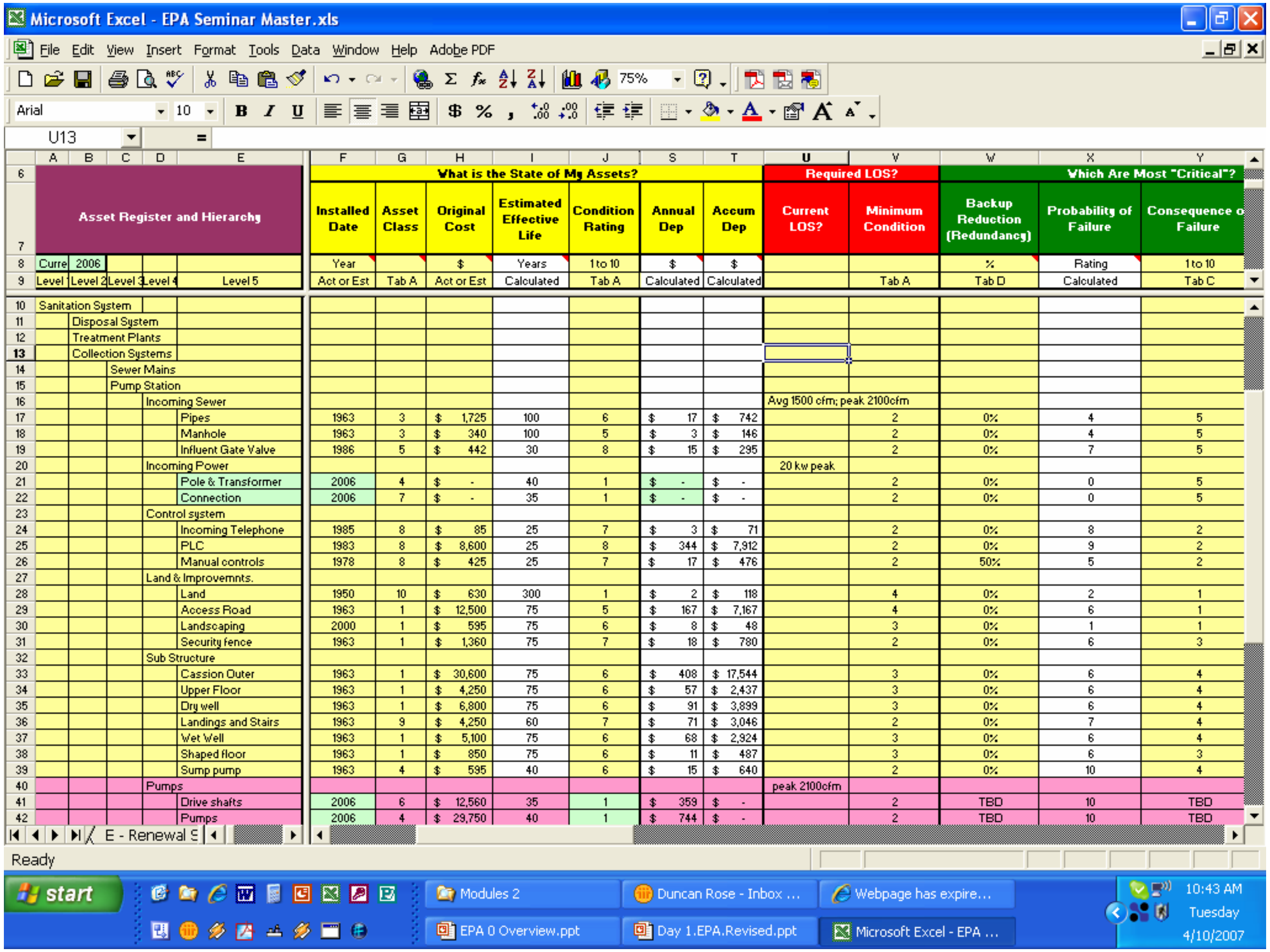
Key Points:·

- Reactive emergency maintenance can be the most expensive type of maintenance and should typically make up no more than 20% to 25% of total maintenance effort
- Preventive and predictive-based pro-active strategies should comprise the bulk of the effort
- Assets, especially dynamic assets, leave discernable clues as to their capacity to perform.
- The most cost effective maintenance strategy for a given asset is determined by the likelihood of failure and the consequence of failure.
- “Run to failure” may well be the most cost-effective maintenance strategy for a given asset, but only when coupled with a carefully developed failure response plan.

Associated Techniques:

- Condition-based monitoring plans and deployment
- Reliability Centered Management
- Root cause analysis
- Asset maintenance strategies (zero breakdown, total productivity, reliability centered maintenance)
- Failure response plans

Tom’s spreadsheet



	A	B	C	D	E	F	G	H	I	J	S	T	U	V	W	X	Y
6	Asset Register and Hierarchy					What is the State of My Assets?							Required LOS?		Which Are Most "Critical"?		
7						Installed Date	Asset Class	Original Cost	Estimated Effective Life	Condition Rating	Annual Dep	Accum Dep	Current LOS?	Minimum Condition	Backup Reduction (Redundancy)	Probability of Failure	Consequence of Failure
8	Curre	2006				Year		$	Years	1 to 10	$	$			%	Rating	1 to 10
9	Level 1	Level 2	Level 3	Level 4	Level 5	Act or Est	Tab A	Act or Est	Calculated	Tab A	Calculated	Calculated		Tab A	Tab D	Calculated	Tab C
10	Sanitation System																
11		Disposal System															
12		Treatment Plants															
13		Collection Systems															
14			Sewer Mains														
15			Pump Station														
16				Incoming Sewer									Avg 1500 cfm; peak 2100cfm				
17					Pipes	1963	3	$ 1,725	100	6	$ 17	$ 742		2	0%	4	5
18					Manhole	1963	3	$ 340	100	5	$ 3	$ 146		2	0%	4	5
19					Influent Gate Valve	1986	5	$ 442	30	8	$ 15	$ 295		2	0%	7	5
20				Incoming Power									20 kw peak				
21					Pole & Transformer	2006	4	$ -	40	1	$ -	$ -		2	0%	0	5
22					Connection	2006	7	$ -	35	1	$ -	$ -		2	0%	0	5
23				Control system													
24					Incoming Telephone	1985	8	$ 85	25	7	$ 3	$ 71		2	0%	8	2
25					PLC	1983	8	$ 8,600	25	8	$ 344	$ 7,912		2	0%	9	2
26					Manual controls	1978	8	$ 425	25	7	$ 17	$ 476		2	50%	5	2
27				Land & Improvemnts.													
28					Land	1950	10	$ 630	300	1	$ 2	$ 118		4	0%	2	1
29					Access Road	1963	1	$ 12,500	75	5	$ 167	$ 7,167		4	0%	6	1
30					Landscaping	2000	1	$ 595	75	6	$ 8	$ 48		3	0%	1	1
31					Security fence	1963	1	$ 1,360	75	7	$ 18	$ 780		2	0%	6	3
32				Sub Structure													
33					Cassion Outer	1963	1	$ 30,600	75	6	$ 408	$ 17,544		3	0%	6	4
34					Upper Floor	1963	1	$ 4,250	75	6	$ 57	$ 2,437		3	0%	6	4
35					Dry well	1963	1	$ 6,800	75	6	$ 91	$ 3,899		3	0%	6	4
36					Landings and Stairs	1963	9	$ 4,250	60	7	$ 71	$ 3,046		2	0%	7	4
37					Wet Well	1963	1	$ 5,100	75	6	$ 68	$ 2,924		3	0%	6	4
38					Shaped floor	1963	1	$ 850	75	6	$ 11	$ 487		3	0%	6	3
39					Sump pump	1963	4	$ 595	40	6	$ 15	$ 640		2	0%	10	4
40				Pumps									peak 2100cfm				
41					Drive shafts	2006	6	$ 12,560	35	1	$ 359	$ -		2	TBD	10	TBD
42					Pumps	2006	4	$ 29,750	40	1	$ 744	$ -		2	TBD	10	TBD